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Air-Conditioning Use in Thai's Household
The Inter-relation of People, Climate and Building Designs

by

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Abstract

The traditional three-way interaction between climate, people and buildings has been discussed over years. Despite of human skin and clothing, buildings are generally interpreted as a third skin which shelter and protect us from the climate conditions. As important as we have to adapt and live with the nature in a harmonious way. Before the cooling technology is widely accepted and adopted in many types of buildings. The natural use of cooling technique was one of the fundamental rules in Thai building designs. As the contexts of social, people, cities have been motivated toward globalization steam, so does Architecture. Soon after the new cooling technology arrived in Thailand, massive transformations were happened or even at the present time. With a precise and controlled indoor climate, it seems to be a desirable solution for people who live in hot humid climate. Taking an aspect of thermal acclimatisation, anew Coolth cute has affected on thermal adaptation in who has become accustomed to air-conditioned environment. This statement might make you have a thought of Thais too far relied on cooling technology. However, from the other aspect, there are criticises on building design where has got influenced form western style which hardly reflect to hot humid climate building design. Are people the victims to Coolth cult or building designs which do not meet comfortably satisfactory environment?

The aim of the air-conditioning use in household study is to take a crucial look at the relationships between occupants and the building. Investigations of patterns of air-conditioning use in occupants and building performance are examined by questionnaires and measurements methods.

- Relations of building locations, building types and air-conditioned room
- Relations of AC operation periods, seasons and occupant factors
- Air-conditioning operation in relation to energy saving aspects
- Influences of microclimate and building designs on thermal comfort level
- Building performance in relation to thermal comfort level in monitored outdoor, indoor environments and air-conditioning performance
- Pattern of air-conditioning use

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First of all, I would like to thank you my supervisors, Dr. Alan Young and Dr. Ben Croxford for their constructive advice and support during my time of study in the Bartlett. Thanks to all participants who completed questionnaires and specially to house owners who took part of house monitoring. Finally, I am grateful to my family for their support during my study and exclusively to my sister for her moral and practical support. This MSc is dedicated to her.

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Chapter 01: Introduction

1.1 Pre-discussion and chapter overview

The traditional three-way interaction between climate, people and buildings has been discussed over years. The relationships between man and buildings have started ever since man is always affected and dictated by climate[1]; as we need protections. Despite of human skin and clothing, buildings are generally interpreted as a third skin which shelter and protect us from the climate conditions. As important as we have to adapt and live with the nature in a harmonious way. Understanding the contexts of climates, environments and human thermal comfort conditions are essential for building design. Therefore, one of the main objectives for buildings is to create comfortable indoors living conditions[2]. In order to offer occupants the best possible indoor conditions of buildings, bioclimatic building design is the fundamental. For instance, utilising natural ventilation for cooling is part of creating comfortable living conditions indoors and other different methods depending on climatic characteristics and locations. However, after the advent of HVAC technology, it had a magnificent impact on architecture and people as well as climate. This technology shows its power on controllable indoor climates with a precise setting comfort level. It occurs that now we are able to control the thermal comfort level as desiring, and independent from climate. HVAC system has become a modifier in building design which the system offers occupants the best indoor conditions instead of relying on bioclimatic building design effects.

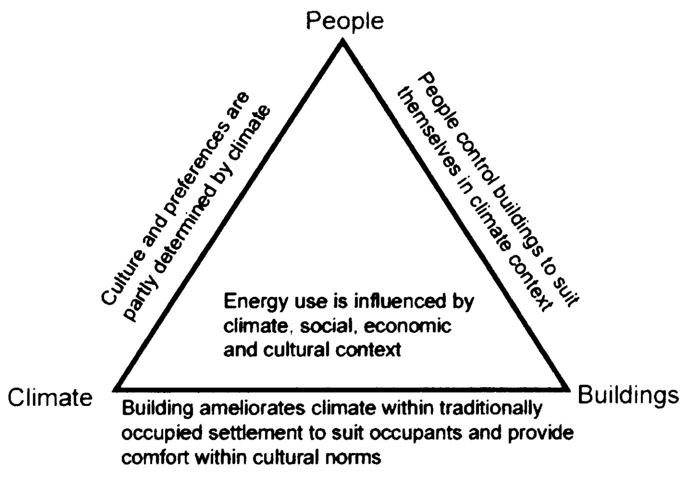

Figure 1.1: The traditional three way interaction between climate, people and buildings.[3]

[1] C.E.P. Brooks, Climate in everyday life, 1950, p.11

[2] S. Yannas, Designing for summer comfort, 2002, p.1

[3] S. Roaf, D. Crichton and F. Nicol, Adapting Buildings and Cities for Climate Change, 2005, p. 217-219

The summary of three key factors in influencing architectural design always interacts as a cycle which can dictate our energy needs. (See figure 1.1) As in general, energy use is influenced by climate, social, economic and culture context.[4] With the use of new modifier, consequently, an increasing of energy use is concerned. Before 1970's oil crisis, we did not realize how the consequence of increasing energy use would affect us until reserved fuel starts to run out. Even though, the advantage of new technology has increased the satisfaction of thermal comfort in occupants. We can not refuse the fact that amount of wasteful energy is produced by operations of the system resulting in CO_2 emission into the atmosphere including CFC from refrigerated cooling devices.

All consequences have caused Green House Effects which lead to global warming in this century. This phenomenon does currently occur across counties and become a major issue on energy conservation. After the oil crisis, the awareness of energy consumption and climate change issues have been increasingly discussed in order to prevent this situation repeated and to find solutions of how to decrease the energy use and learn how use technology more effectively, as well as to improve the environment. It can be confirmed that the advent of HVAC technology has affected on a vast scale, critically on climate change and building design which rather takes HVAC design factors into account than concern the climate conditions. Furthermore, the effect of HVAC use also has occurred on thermal acclimatisation of occupants towards a new type of environment.

The same situations of changing in climate, building designs and thermal acclimatisation, as well, occurred in Thailand. In hot humid climate, cooling technology is found to be a desirable item as its benefit to maintain the best productivity and performance, especially in a work environment. By flowing of global culture[5], this has caused: the rise of individualism, the introduction of industrialised building products and the introduction of global housing imagery. We once used to have a great deal how to handle the extreme weather condition as bioclimatic building design was the fundamental. However, since we prefer to get pleasure from the new technology, we have lost pleasure in natural environment. Buildings are designed without a consideration of climatic characteristics and tend to have Western-oriented building designs, which can be particularly found in main cities, such as Bangkok. With a great concern in capitalisation influence into other areas of Thailand, the same crucial issue can be repeated. As a consequence, the worst is to come on energy consumption.

This chapter aims to raise issues regarding what have been affected by HVAC technology as in the global scale. Specifically in Thailand, the scope of study is established in order to focus on effects of cooling technology use. Following this, the aims and objective of the study are described as well as the overall structure and directions are to be clarified as in a chapter-by-

[4] S. Roaf, D. Crichton and F. Nicol, Adapting Buildings and Cities for Climate Change, 2005, p. 217-219

[5] D. O'Brien, Moderated influence: Globalisation and Thai housing, 2001, p.59

chapter summary. Furthermore, a methodological overview is presented.

1.2 Aims and objective of study

Referring to the traditional three way interaction between climate, people and buildings, the effects of cooling technology in Thailand have obviously caused changes in the chain interaction. As there are evidences of changes in climates which have been measured and verified. The aims of this study is first to further examine those particular changes in architecture and thermal acclimatisation in Thais by based on climate study, and to investigate the air-conditioning use in Thais in the current situation in relation to energy consumption aspect. In order to achieve these aims, the following objectives have been set out.

- Investigate the current situation of air-conditioning use in Thailand
- Examine changes in thermal acclimatisation towards air-conditioned environment
- Present building design approaches before and after the advert of cooling technology
- Examine the relationships between building design and thermal comfort in the age of cooling technology

1.3 Structure of the study and methodological overview

The study consists of six chapters and uses a mixed approach of methodology in the study. The main methods are

- Review of existing literature
- Analyse primary data from survey and measurement results.

The next chapters can be briefly summarised, as followed;

Chapter 02: Air conditioning and Thai society

This chapter introduces 'Coolth' cult. The study examines the area of researches in office workers who accustom to air-conditioned environment by pointing out the issue of adaptation of people in work environment has affected to thermal acclimatisation and the issue of energy consumption.

Chapter 03: Evolution of Thai dwelling

The chapter take a closer look on bioclimatic building design as back ground study in Thai tradition dwelling as an overall where Bangkok is a scope of the study. Climatic and thermal comfort studies are included. In new contexts of social, people, economics, as a consequent, the transformations in Thai building designs is occurred. This chapter mainly is literature reviews.

Chapter 04: Methodology in Air Conditioning Use in Thais' Household Survey and Monitoring

The chapter aims to describe the methods of the study in air-conditioning use in Thai's household, as survey and measurements are used tools for investigations.

Chapter 05: Results and discussion on Air-conditioning use in household

Revealing the results from subjected surveys is discussed in order to find the ways of air-conditioners are operated in typical household; operated room, pattern of use and air-conditioner setting. Apart from investigating in these areas, attitude and opinion on air-conditioning use in participants are revealed. These aspects are lead to energy consumption issue. As the chapter aims to reveal the air-conditioning use, the study is carried on in a greater detail of air-conditioning use by monitoring in selected houses. Efficient in building designs are evaluated by comparing building performance in non and air-conditioned rooms to outdoor ambient conditions; dry-bulb temperature (c), relative humidity (%) and absolute humidity (g/kg).

Chapter 06: Conclusions

Chapter 02: Air conditioning and Thai society

2.1 Pre- discussion and chapter overview

"*Practically every action of human life is directly affected by the climate. The food we eat, the clothes we wear, the house we dwell in, the work we do, are all dominated by the climate in which we have the good or bad fortune to live....Our day-to-day activities are more or less affected by the day-to-day weather, but the general pattern of our lives is governed rather by the climate*", Brooks states [6]

Although, the climate is the main influence to the way we live. In general, the outdoor and indoor is what we are accustomed to. These days, when we regard indoor environment as natural or air conditioned. These informal terms become recognizable in Thais rather than natural and mechanical ventilation in a more technical term use. Air conditioning climate seem to be another main influence to affecting the way we live nowadays. Being accustomed to air-conditioned environment seems to be perceived as the third type of environment in Thai societies. Particularly, Bangkok has an intensive use of air conditioning which is not applied only to buildings, but also transportations in private and public sectors.

In some particular cases, especially Bangkokians, some of them could hardly experience outdoor or non air conditioned environment in one day. Taking the office worker case as an example, he or she starts the day off going to work using an air-conditioned vehicle. Soon after they arrived, working in an air-conditioned workplace. Then after work, getting back home in the same vehicle. Later on spending almost of the rest of day in air conditioned room. Moreover, during the weekends, they prefer having a leisure activities in a place where may be air-conditioned as well.

Since the scale of air conditioning use is widely used in many sectors, this kind of experience is also seen in other groups; i.e. workers in other sectors, even in students. These days, our day-to-day activities explore more and more in air conditioned environment rather in natural environment. Are our lives being governed by air conditioned environment rather by the climate? This chapter reveals air conditioning use in Thais concerning energy consumption and air conditioner acclimatisation. It also views the background of 'Coolth cult'.

[6] C.E.P. Brooks, Climate in Everyday Life, 1950, p.11

2.2 The start of Coolth cult

The invention of air conditioners cannot be certified a certain date.[7] At first, the invention was not intended to be designed as an air conditioning system as seen in the present day. The first use was for cooling the food at the turn of the 20th century. It was started from an experiment of evaporating ether under a partial vacuum by William Cullen, Glasgow University in 1748. Later Oliver Evans caused water to freeze using a similar method in 1805. Also followed with other series of experiments by others, until 1834, Jacob Perkins succeeded in developing a closed cycle system for freezing mixtures and the great natural ice trade. In the mid of 1840s John Gorrie was the first person who pioneered the use of room coolers. Unfortunately, the idea did not sound convinced by people at the time. Later in 1877 it became a great deal for British exporting meat to America using refrigerated ships. An inhabitable air conditioned room did not yet exist.

Gorrie would not believe that his invention has dictated the forms of buildings around the world.[8] Early models of air conditioned buildings were office buildings in the UK and the United States in the 1890s. The experiment moved on to larger buildings, such as hotels, in the United States which were being more routinely air-conditioned[9]. Not until 1950s air conditioning was a significant role in commercial and residential buildings, due to the limitations of industrial applications. Combining new and existing housing, air conditioning saturation has increased from 12 per cent of occupied US housing units in 1960 to 36 per cent in 1970, 55 per cent in 1980 to 64 per cent in 1992. Before the invention of compressor air conditioning, the residential buildings are designed to respond to the local climate conditions. Though, the demands in air conditioning were constantly increased. [10] Ever since, Coolth cult was growing in Americans.

2.3 Coolth cult

Air conditioning use is not only happened over the western countries, but also in Asian regions. Before the 1950s, Japanese residential buildings typically used the primary heating devices in order to keep warm in the cool weather. Passing on a new cooling technology, the United State has motivated Japanese technology.[11] By the 1980s, heat pump systems (i.e. combination air conditioning and heating systems) appeared on the market. Though there is no clear evidence or a certified certain date of crossing Coolth cult between the two

[7] H. M. Will, The First Century of Air Conditioning, ASHRAE, 1998

[8] S. Roaf, D. Crichton and F. Nicol ,Adapting Buildings and Cities for Climate Change, 2005, p. 217-219

[9] IBID, p.219

[10] W. Kempton and L. Lutzenhiser, Introduction, 1992, p.172

[11] Thai HVAC, 2005

continents, the popularity of heat pump system use has constantly increased in Japan since the 1960s.[12] It is very interesting to determine that the use of air conditioning in Japanese is not only for ease thermal discomfort but it is evaluated as a luxurious item according the results of survey. This data reveals this cult can be more than thermal comfort aspects but including socio aspects. When cooling technology has arrived in Thailand, Thais seem to familiarize to a new cult as a new life style. How do we reflect the new technology of cooling use?

2.4 Air conditioning use in Thais

In Air conditioning age, especially in urban cities, one person is unlikely able to avoid to experience air conditioned environments. The evidences of air conditioning use in Thais are reflected from everyday life activities. Air conditioning use appears to affect the way we dress, the building we build, the environment at work and transportations, even since we accept the cooling technology from The United State and Japan[13]. Commonly, typical air conditioned environment is operated in commercial and office buildings. Currently, air conditioning use is increasingly operated in other type of buildings, i.e. government offices, schools and especially households. What is the reason of the increasing use of air conditioning?

Various studies in air conditioned buildings are conducted, particularly in office buildings, in a field study of thermal comfort. It is said that air conditioned use in a working environment will increase or obtain a good rate of productivities. An idea of working in a precise setting thermal comfort level seems to be a great advantage. On the other hand, there is a great concern on energy consumption as we try to adjust hot humid to be more temperate environment. This has an immense effect on the global environment as there is an increase in CO_2 emissions into the atmosphere. Regarding climate, the pattern of seasons have definitely influence hot and cold effects on us. Therefore, the way of air conditioning operation in conjunction with seasons also significantly impact on energy consumption. To achieve a sensible way of air conditioning operation in winter, the system cannot be operated when the weather conditions are comfortable enough for occupants. However, it turns to be that air conditioners are operated all year round, mostly in Bangkok. By not utilizing the natural ventilation for cooling the buildings, as a result there are amount of wasteful energy. This is not only one issue of energy consumption concern, but also the issue of those people who become accustomed to the more temperate environment. As far as air conditioner acclimatisation behaviour is concerned, these people are likely to have air conditioners at home and turn it on

[12] H. Fujii and L. Lutzenhiser, Japanese residential air conditioning: natural cooling and intelligent system, 1992, p.221-222

[13] Thai HVAC, 2005

systematically while they are at home including at night time.[14]

Referring to the study in 1992 by Busch, people who work in air-conditioned buildings have around 40 per cent of 'usually' use of air conditioning at home. (See table 2.1) Then, compare this case with the people work in natural ventilated buildings; there is around 24 per cent of 'usually' use of air conditioning at their home. The result shows the trend of air conditioning use at home is greater when a home occupant works in an air conditioned building. Therefore, the longer hours in air conditioned environment are extended from work to household, which means the fewer hours in natural environment are explored.

Background of Occupants according to office buildings	**Level of household air-conditioning use**			
	Never (%)	Seldom (%)	**Usually (%)**	Always (%)
Air conditioned buildings	53.1	3.5	**38.3**	5.1
Naturally ventilated buildings	72.1	2.1	**24.2**	1.6

Table 2.1: Use of air conditioning in household[15]

2.5 Discussion and conclusions

As discussed, there is an expansion of air conditioning use in many sectors, including commercial and office buildings. Consequently, the level of air conditioner acclimatisation in Thais increased. Once we tend to prefer air conditioned environment than natural one. Later on, it could lead to an avoidance of adjusting into hot humid environment. Instead of that, we tend to seek for the place where is air conditioned. Even afford to have an air-conditioner at home. This could become a phenomenon in the near future when new generations were raised and fully accustomed to air conditioned environment than natural environment. It is hard to deny that air conditioning use can satisfy occupants to ease thermal discomfort, especially in hot humid climates. With a precise and controlled indoor climate, it seems to be a desirable solution since we are accustomed to air conditioned environment. This statement might make you have a thought of Thais too far relied on cooling technology. Are they the victims to Coolth cult or poor building designs which do not meet comfortably satisfactory environment? Therefore, in chapter 03, we take a more crucial look at influences in Thai dwelling designs, the level of thermal comfort in Thais and how environmentally responsive design they are.

[14] N. Yamtraipat, J. Kheari, J. Hirunladh, Thermal comfort standards for air-conditioned buildings in hot and humid Thailand considering additional factors of acclimatisation and education level, 2005, p.512

[15] J. F. Busch, A tale of two populations: thermal comfort in air conditioned and natural ventilated offices in Thailand, 1992, p.246

Chapter 03: Evolution in Thai dwellings

3.1 Pre-discussion and chapter overview

Over hundreds years ago, the evidence of Thai way of living was commonly found on mural paintings in Thai temples. The paintings also revealed architectural features. Before the Second World War, it was the period that Thai houses were still commonly found in all regions. There was no radical change in physical form of the building. The tallest buildings, at the time, were religious buildings or palaces as demonstrated in figure 3.1. Not until the 21st century, a major transformation was obviously seen in Thai houses in which many evidences of Thai architecture changes were found. Likewise, the identity of building characteristics had vanished; it only reflected a little when the traditional wisdom was inherent[16].

Figure 3.1: Evidences of changes in Thai architecture[17]

[16] D. S. Parker, Measured Air-Conditioning and Thermal Performance of Thai Residential Building, 1995, p.907

[17] Picture sources: see references

"As the Third World traverses the path of modernization, it appears almost of inevitable that buildings will increasingly be air-conditioned to meet the higher standards of amenity that 'modernity' implies. One need only travel to the burgeoning cities of the tropics to witness the transformation from vernacular, open designs utilizing natural techniques for cooling, to closed-box, conditional architecture"[18]

As Busch gave options on Thai architectural transformations, this message may cause an infuriation. However, it gives a strong reflection for the current situation. Before the cooling technology is widely accepted and adopted in many types of buildings. The natural use of cooling technique was one of the fundamental rules in Thai building designs. This study has no intention to plead with everyone to come back or to live like in the old days when the contexts have changed. It is to consider the flowing of global culture and adaptation in culture. As the contexts of social, people, cities have been motivated toward globalization steam, so does Architecture. Changes do not imply that we have to abandon or overlook the old wisdom of how to adapt and survive in hot humid climate.

This chapter represents the fundamental in bioclimatic building design in Thai traditional dwellings. It is worthwhile to investigate major factors influencing building forms and the evolution of Thai architecture; i.e. background studies on geometry, climatic characteristics, and thermal comfort in Thailand. In addition, the topic of evolution in Thai architecture is added in order to demonstrate a timeline of buildings transformations from utilizing natural ventilation to replying on cooling system in the present day.

3.2 Influences in Thai traditional housing design

Drew and Fry[19]state that there are three main considerations influencing architectural design in the tropics, as shown below. The three keys always interact as a cycle which dictates our energy needs as discussed in chapter 01.

- People and their needs
- Climate and its attendant ills
- Materials and the mean of building

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[17] Picture sources: see references

[18] J. F. Busch, A tale of two populations: thermal comfort in air conditioned and natural ventilated offices in Thailand, 1992, p.235

[19] M. Fry and J. Drew, Tropical Architecture in the Humid Zone, 1956, p.23

Influences in Thai architecture are in common as Drew and Fry study. Although, there are common influences among tropical architecture, there are five influences[20] of assorted Thai vernacular housings, as follow:

- Geographical features of place
- Climate
- Religion and beliefs
- Socio culture and ethnic backgrounds
- Construction technologies and materials

We can consider buildings as the third skin since we need a shelter to protect us from discomfort conditions in hot humid climates. Rapoport[21] suggests that climates and materials are the two main architectural of building forms development. That is, forms of the building are a product of the two modifiers. Apart from building study, in following sections also focus on climatic characteristic and thermal comfort studies in correspondingly to bioclimatic building designs.

3.3 Climatic characteristics

Thailand is situated between 5°37’ and 20°27’ Latitude North and between 97°22’ and 105°37’ Longitude East. The geography of Thailand, in general, is divided into six regions. There are two criterions for regional divisions. The first criterion is the orientation of regional location according to the point of reference on the map of Thailand. As the north, the northeast, the central, the east, the west and the south parts are officially termed. The other one is the similarity in culture, economics and topography. The latter is commonly recognized as each region has its own characteristic in life style and culture aspects in relation to history and ethnic backgrounds.

According to the geography, Thailand typical climate can be classified as tropical humid climates. A board definition of tropical humid climates is described as

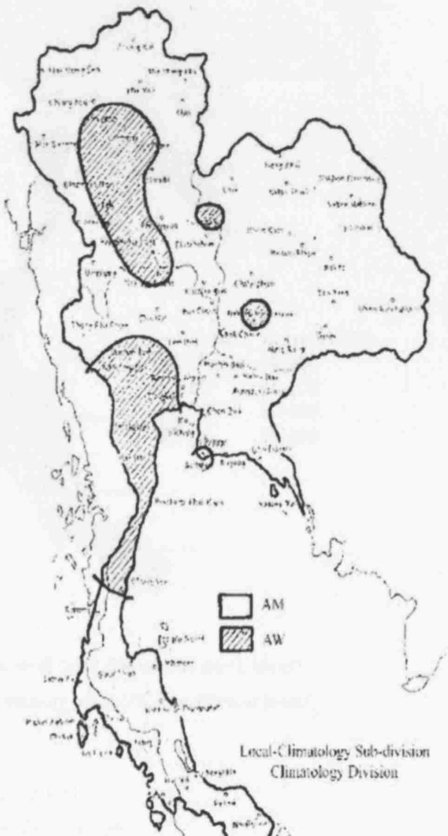

Figure 3.2: Thailand climate classification

[20] V. Srisuwat, Assorted vernacular housings, 2000, p.23, Thai document
Baan-Thai (Thai traditional houses), 1995, p.41, Thai document

[21] A. Rapoport, House form and Culture, 1969

"...having a high humidity throughout the year, even in the dry season, a smaller variation in day and night temperature."[22] However, Thailand climate is subdivided into a tropical monsoon climate (*Am*) and a tropical savannah climate (*Aw*). (See figure 3.2)[23]

A recent research of Thailand climatic zones[24] reviews the data of 18 years of ambient air temperature and relative humidity which aiming to classify the climatic conditions of different locations. The scale of national climate has been digested into regional climates as the data has become relatively corresponding to ambient local conditions. (See figure 3.3, 3.4)[25]

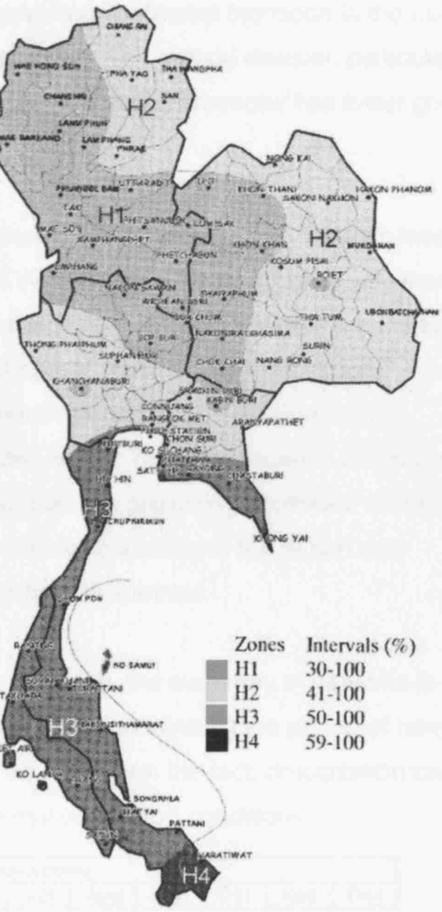

Figure 3.3 (Left): Map of air temperature Zones (Based on 2.5% significant level)

Figure 3.4 (Right): Map of relative humidity Zones (Based on 2.5% significant level)

[22] M. Fry and J. Drew, Tropical Architecture in the Humid Zone, 1956, p.30-31

[23] J. Khedari, A. Sangprajak and J. Hirunlabh, Thailand climatic zones, 2002, p.269

"The tropical humid climates are not noted not so much for warmth as for lack of coldness. The sun is high in the sky everyday of the year. The climates are classified into three types on the basis of the quantity and regime of annual rainfall.

- *The type (Af) experiences relatively abundant rainfall every month of the year.*
- *The type (Am) has a short dry season but very rainy wet season.*
- *The type (Aw) is characterized by a longer dry season and a prominent but not extraordinary wet season."*

[24] IBID. p.267-280

[25] IBID, p.275-276

Annually, the overall climate conditions in all regions show that the upper part of country has the lowest of lower boundary dry-bulb temperature and relative humidity at 12°C and 30% in order. Whereas in the southern areas has a highest of lower boundary dry-bulb temperature and relative humidity at 201°C and 59%, respectively. As for the upper boundary in two parameters can go up to 38 1°C and 100% RH in all regions, depending on the seasons.

In general, there are three different seasons commonly recognized; summer, rainy and winter. However, the patterns of season are vaguely varied in regions due to the influences of monsoon[26]. The two prevailing winds from the southwest and the northeast directions are main influences in local climates. Because of the prevailing southwest monsoon in the rainy season, rainfall peaks occurring from August to September. The natural disaster, particularly flood is often occurred in the central regions where the geography character has lower ground level than others.

The other is the prevailing northeast monsoon in which the amount of rainfall is much less in the rainy season and December is the driest month. As a result, drought is commonly found in the north and the northeast regions. The summer season can be considered as a transitional period, as the primary influence shifts from the northeast to the southwest monsoon. Occurring in all regions, it makes April the hottest month as usual.[27] In relation to the geography, the southern regions are the most effected areas. The local climates are not only influenced by the two main prevailing monsoons, but also the prevailing southeast monsoon occurring during the winter season. Therefore, high rainfall occurring in the region and ambient temperature in winter is not much saturated from in summer.

In order to understand the overall season pattern in Thailand, the summary of seasons in all regions is represented in table 3.1. The seasonal pattern demonstrating the period of rainy season is longer than other two seasons in all regions. Based on the fact, precipitation causes high temperature and humidity results in typical thermal discomfort conditions.

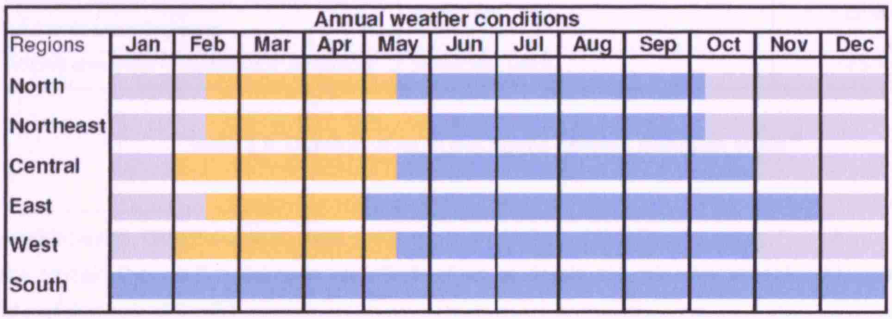

Table 3.1: The summary of seasons in all regions

(Key: Orange, Blue, Grey shades are represented as summer, rainy and winter seasons, respectively)

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[26] M. Srisuwan, The study of Air Flow Patterns in Relation to Building Wall Openings for Tropical Climate of Thailand, 2000, p.10-11

[27] J. Khedari, A. Sangprajak and J. Hirunlabh, Thailand climatic zones, 2002, p.270-271

3.4 Thermal comfort

The definition of thermal comfort has been given as *'that state of mind in which satisfaction is expressed with the thermal environment.'*[28] Air temperature, radiant temperature, humidity and air movement are considered as the four basic environmental variables that have effects on human response to thermal environment. Not only the thermal elements, but also the metabolic heat is generated by activity and clothing level.[29] However, there is not an exact concept, nor does it occur at an exact temperature or relative humidity.[30] At the time, Thai comfort standard was being currently accepted level of 26.11°C as it adopted from ASHARE (1989).This comfort standard has been established based on findings of American and European people living in the region of around 40 degrees latitude and who are used to mechanically conditioned buildings.[31] Although there is a rule of thumb proposes to extend the comfort zone by 1°C for being 12 degree latitude closer to the equator. A sensitivity of thermal comfort in particular areas is essential.

3.4.1 Comfort zone according to thermal acclimatisation background

Various studies confirm that preferences of people in different locations vary in terms of the long-term experience of a humid and warmer climate several generations. This may result in people of that environment having a tolerance to higher temperatures as compared with people in colder regions.[32] Table 3.2 shows a range of comfort zone of various studies in non-air-conditioned buildings. Comparing with the early years, comfort zone was differently defined from the recent year results.

Year	Research groups	Studies	Comfort zone (°C)
1925	Haughten, Yaglou and Miler	The Effective Temperature index	19 – 26
1960	Webb C.G.	The Equatorial Comfort index	22 – 27
1962	Vernon	The corrected Effective Temperature	22 – 27
1963	Olgray, V.	The Bioclimatic Chart	22 – 27
1981	American Society of Heating, Refrigerating and Air-Conditioning Engineers	ASHRAE	22.6 – 26
1990	ASEAN committee in Science and Technology	Mohoney Table	23.7 - 30

Table 3.2: Comfort zone in hot humid climate, Bangkok study[33]

[28] Environmental Design, CIBSE Guide A, 1999, p.1.7

[29] K. Parsons, Human Thermal Environments: the effects of hot, moderate and cold environments on human health, comfort and performance, 2003, P.1

[30] N. Yamtraipat, J. Kheari and J. Hirunladh, Thermal comfort standards for air-conditioned buildings in hot and humid Thailand considering additional factors of acclimatisation and education level, 2005, p.504

[31] Climate and Design Strategies for Beijing and Shanghai, 1998

[32] N. Yamtraipat, J. Kheari and J. Hirunladh, Thermal comfort standards for air-conditioned buildings in hot and humid Thailand considering additional factors of acclimatisation and education level, 2005, p.504-505

[33] Passive ventilation & passive cooling, 2004, p.1.6, Thai document

As far as air-conditioner acclimatisation is concerned, the investigation of comfort zone in air-conditioned buildings is carried out. In 1992, Busch[34] study reveals that thermal comfort in office workers who are accustomed to air-conditioned and natural ventilated environment are higher than the standard suggestion. The surveys were conducted in Bangkok which over 1100 office workers participated. As the survey results show that in air-conditioned buildings have the lower boundary of comfort zone is about 22 °C and the upper boundary reaches nearly 28 °C. Whereas, in natural ventilated buildings have an undefined lower boundary of comfort zone and the upper boundary is approximately 31 °C. This piece of evidence was published in Energy and Building as Burch had an intention to announce the differences in temperate and hot humid Thailand thermal comfort and raised this issue to the public.

The recent study of Thai thermal comfort in air-conditioned buildings was conducted in three regions of Thailand. The study considered the local thermal comfort zone in relation to the local climate. The results revealed the verifications of the relationships of thermal comfort and local climates as demonstrated in table 3.3. After individual results are verified, the acceptably average temperature for all surveyed regions is made to 24-26 °C. The intention is that the new range will be appropriately used as a single comfort value in the future thermal comfort standard regulation. Therefore, the considerations of thermal acclimatisation background of occupants is essential to be examined in order to specify comfort zone either none or air-conditioned building.

Surveyed region	Area	Dry-bulb temperature (°C)	Relative humidity (%)	Comfort Zone in air-conditioned buildings (°C)
Northern	Chiang Mai	12-38	30-100	24-26 c
North-eastern	Mahasarakham	16-38	41-100	24.5-27.4 c
Central	Bangkok	20-38	41-100	24.5-27.4 c
Southern	Prachuabkirikhuan	20-38	50-100	23.7-26.4 c

Table 3.3: The summary of seasons in all regions

3.4.2 Comfort zone and energy consumption issue

Now let we move on air-conditioned buildings comfort zone. According to the early study by Busch in 1992, the recent result in Thai thermal comfort in air-conditioned buildings has shown a new average temperature for acceptability. Comparing of the two studies in air-conditioned buildings, the lower boundary temperature has increased from 22 to 24 °C and the upper boundary temperature is shifted down from 28 to 26 °C. The main points of finding a

[34] J. F. Busch, A tale of two populations: thermal comfort in air conditioned and natural ventilated offices in Thailand, 1992, p.244

change in Thai thermal comfort and dropping a temperate comfort standard are critically linked to energy consumption in air-conditioned buildings. Although, air conditioning design and operation are based upon guidelines and being developed through thermal comfort research on temperate climates. Adopting temperate thermal comfort standard in hot humid climate ought to be justified. The study also suggests that the means to set a highest boundary temperature as a temperature set-point in general building. Consequently it will help reducing electricity consumption in air-conditioned building. A mean energy saving can be approximated at 6.14% when applying a 1 °C increase of the set-point. It means that setting the room temperature lower than the lowest boundary temperature will cause air conditioning system to consume more electricity power.

3.5 Bioclimatic building designs

Bioclimatic building designs were the fundamental rules in traditional Thai architecture before the Air-conditioning age. Determining residential building designs, the buildings can be classified into four typical types in relation to regions and socio background. (See figure 3.5) The buildings were designed to determine the climatic conditions by utilising natural ventilation for cooling and reducing discomfort due to humidity. A rule of thumb is to simply and logically respond to the environmental problems. Although, feature forms of the building are different in each of regions, the principal elements of the building are the same as the use of high pitch roofs and elevated house platforms[35].

Taking a crucial look at one particular case in the central region, the housing is designed into small units which are all situated on an elevated open air platform. The numbers of unit depend on the size of the family and the complexity of building uses. In general, within one unit is used for a specific living accommodation; i.e. sleeping space and kitchen, living areas are commonly occupied on sheltered decks where the space is a linking space from the open platform to units (transitional space). It is often the deck space used for other activities which can be considered as a multifunctional space. Therefore, the elevated platform of dwelling unit usually consists of broad open desk area, and opened veranda which are connected to enclosed rooms[36].

[35] C. Klunyanamit, Traditional Thai Architecture, 1996, p.115, Thai document

[36] T. Buranasomphob, Traditional Thai House and Energy consumption,1998

Figure 3.5: Four typical types of residential buildings according to regions[37]

In bioclimatic building designs of traditional Thai house, orientation of the building has significant impact on utilising natural ventilation and reducing heat gain. Thus, the long axis of building is essentially paralleled to east-west sun axis. The logic behind of high pitch roof design is to foster faster water drainage in rainy seasons. Moreover, the empty space under roof space creates a stack effect (vertical ventilation) to drive the hot air out of the building by the cool air from the room through gaps of roof tiles. The design of small volume of unit with openings of on all side of wall panels actuates a rate of flow (horizontal ventilation) which ventilates the excess of hot air temperature and eliminates dampness. [38] The benefit of separated unit design is the use of overshadowing from one unit to shade another unit, in order to reduce amount of sunlight which reflects directly on wall panels. In addition, long overhangs from the roof provide sun protections and rain blowing into the building. However, having long overhangs is disadvantage to gain natural sun light. Therefore, tall windows are designed for in order to take advantage of prevailing wind, considering of opening positions in

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[37] Picture sources: see references

[38] C. Klunyanamit, Traditional Thai Architecture, 1996, p.119, Thai document

relation to the wind directions. Trickle ventilation and night cooling is employed through slots above windows and doors while they are closed.

The other element of building which helps reduce heat gain during the daytime and heat dissipation at night is the material of building construction. Wood and clay tiles were commonly used as their performance has low heat conductivity and contribute good insulation against the sun. Moreover, both materials are also easy to repair and replaced by local material sources.[39] Although the building design itself is being passive, the surroundings are essential to enhance the cooling in the building. Particularly, vegetations give extra shading on the building envelope and create a cool microclimate.

Figure 3.6: Bioclimatic building designs in traditional Thai dwelling units[40]

For all time, Nature has been influencing on the way Thais adaptation and dictates on their living. Designing of Thai house is dictated by the sun orientation as well. The orientation of the

[39] T. Buranasomphob, Traditional Thai House and Energy consumption,1998

[40] Picture sources: see references

kitchen is west where the heat of sun radiation is used for pasteurise the space and eliminate dampness from cooking activities. During the day, open platform and living units are the most part to get heated from the sun radiation; therefore, the beneath platform space is normally occupied for various activities when it is not affected by flood. In addition, local wind and evaporative cooling from the ground retains thermal comfort level.

Figure 3.7: Changes in Thai dwelling design[41]

Because of the influences of colonial styles via neighbouring colonies on Thailand, the turning point of transformation in traditional house characteristics in other regions was found. Bangkok was one of the very first nations to receive and adopt Western building style. In addition, the changes were not only found in typical house, but also in temples and palaces.[42] As a consequence of centralised influence in most of regions, it is rather hard to distinguish the identity of building characteristic as where it was located, as show in figure 3.7. Moreover,

[41] Picture sources: see references
[42] C. Klunyanamit, Traditional Thai Architecture, 1996, p.116, Thai document

wooden materials were still mainly used for constructions and decorations. With regard to adaptive building designs, nonetheless, the new style of building was adapted into more suitable for hot humid climate where windows and shading design were used for natural ventilation and reducing sun penetration, respectively.

Traditional Thai house was developed to correspond the way of living in agriculture society. As Thailand has a direction of development towards industrial socials and widely communicate with other countries. As a consequence, influences from foreign culture have an effect on Thai life style. The context of the traditional housing does not long suit urban contexts where commercial and industrial activities are taken. Moreover, effects of rising population rate and demand of land use had been increased. Furthermore there was the lack of wood supply for building construction as deforestation worsened.

Figure 3.8: The current Thai architecture[43]

[43] Picture sources: see references

In order to respond to the new context of the city and new modern life style, the contemporary house had replaced the traditional house. The rapid growth of economy in 1983[44], it was considered the golden moment of Thai architecture. Numerous buildings were constructed. Forms of building were changed into more Western architecture appearance as well as materials of building. Western style detached houses, row houses, townhouses and high rise accommodations are commonly built.

In addition, a compact plan which all room was enclosed with having less circulation space is designed to link the rooms. The buildings become air-tight space and rather solid appearance in comparison to the traditional Thai houses. Moreover, awareness of utilising natural ventilation and reducing heat gain again is overlooked. With regardless of the hot humid climate, building designs consequently lead to thermal discomfort. When cooling technology is available in domestic sectors, particularly in urban area, it is found that 90% of urban indoor environments are air-conditioned according to a recent study in 2001.[45] Considering the fact that, Bangkok has a highest density of population and land use,[46] the shocking percentage on air-conditioning use certainly reflects to the amount of energy consumption. However, since 1992, a pioneer of bringing back and conserve traditional Thai architecture[47] has been campaigned with a concern of knowledge losing descending from generations to generations in traditional Thai architecture. As a consequence, bioclimatic building designs had reappeared to be an essential issue once again which have a further emphasis on passive and low energy building design approach.

3.6 Discussion and conclusions

Because of the thoughtful wisdom in traditional Thai housing design, there are many concerns on the lost of knowledge which is not yet fully revealed and transferred to the later generations. Modernisation has almost taken away Thais' identity in many ways. Bringing back the principles of bioclimatic building design will optimistically enhance and give back the identity in Thai architecture. We have to accept the fact that the context of city has been changed towards urbanisation. The old context from agriculture society would not fit in the new context of cities and people. Dense area in large cities, particularly in Bangkok, where utilising natural ventilation for cooling may be not an effective way due to obstruction of wind by high rise buildings. An alternative cooling is employed to keep thermal comfort level; air-conditioners become an ordinary appliance in urban household. Typical air-conditioning uses are found in the offices and the commercial buildings. As discussed in chapter 02, the

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[44] P. Tiptat, Siam architects: fundamental, roles, achievement and concept, 1996, p.256, Thai document

[45] C. Tantasavasdi, J. Srebric and Q. Chen, Natural ventilation design for houses in Thailand, 2001, p.815

[46] Key statistic of Thailand, 2004, Thai document

[47] Architectural heritage in Thailand, 2005, p.9, Thai document

increase of air-conditioning use in household is concerned as crucial as the increase of energy consumption. Also, passive and low energy building design becomes another important issue to be considered in a new building design. Therefore, the compromises of indoor living are made by utilising natural ventilation and creating an effective building envelope in order to reduce the amount of energy consumption. Although broad principles are recommended in many publications, it is essential to investigate into further details which will take a crucial look at the relationships between occupants and the building. Therefore, the study in air-conditioning use in household is carried out in chapter 04 and 05 as they are aimed to investigate the pattern of air-conditioning use in occupants and building performance.

Chapter 04:

Methodology in Air Conditioning Use in Thais' Household Survey and Measurements

4.1 Pre-discussion and chapter overview

In the current situation when the use of air-conditioners has critically affected Thai thermal acclimatisation, particularly in those of who are accustomed to air-conditioned environment. Previous researches confirm that thermal comfort level at the upper limit temperature in a person who is accustomed to air-conditioned environment is lower than a person who is accustomed to naturally-ventilated environment. Air-conditioner acclimatisation behaviour at work environment can lead to an increasing air-conditioning use in residential buildings which consequently affects the amount of energy consumption.

The aim of the air-conditioning use in household study is to take a crucial look at the relationships between occupants and the building. Investigations of patterns of air-conditioning use in occupants and building performance are examined by questionnaires and measurements methods. The survey of air-conditioning in household is conducted with the purpose of finding how air-conditioners are operated in typical household; operated room, pattern of use and air-conditioner setting.

Apart from investigating in these areas, attitude and opinion on air-conditioning use of participants are revealed. These aspects are led to energy consumption issues. Furthermore, the study is carried out in a greater detail of air-conditioning use by monitoring in selected houses. Efficient in building designs are evaluated by comparing building performance both in non air-conditioned and air-conditioned rooms to outdoor ambient conditions; dry-bulb temperature (^{o}C), relative humidity (%) and absolute humidity (g/kg).

Building performance assessment methods are the main framework of the study, though, surveys and measurements are primary methods in the investigations of air-conditioning use in Thais' household. The study also takes a closer look at building design analysis which is related to the way of minimising cooling energy. Verifications can reveal how well thermal performance in the monitored houses are as results from subjected surveys and monitoring data are to be digested and discussed in chapter 05.

4.2 Methodology in air-conditioning use in household survey

4.2.1 Aims and objective of survey

In the first part of investigation, it is aimed to examine the air-conditioning use in household of participants who have a background of air-conditioning use in office. Questionnaire forms are particularly used in house air-conditioning use surveys. The objective of survey is set to reveal the results of which have three main aspects:

- Relations of building locations, building types and air-conditioned room
- Relations of AC operation periods, seasons and occupant factors
- Air-conditioning operation in relation to energy saving aspects

4.2.2 Questionnaires

50 questionnaires are distributed to the target group as aiming at participants who are accustomed to air-conditioned environment in order to achieve the objective. The subjects of the survey questions are listed below. (Appendix B: an example of questionnaire form)

- General information of participants; i.e. gender, age and member of family
- Building descriptions; location (sort by postcode system), type of building, number of storeys and typical air-conditioned rooms
- A database of number and type of air-conditioning units, including settings
- Pattern of air-conditioning operation in accordance with daily activities and seasons
- Thermal comfort factors; i.e. clothing level and activities (in relation to air conditioned rooms)
- Awareness of reducing energy consumption for air-conditioning use

4.3 Methodology in air-conditioning use in household measurements

4.3.1 Aims and objective of measurements

In order to carry out the investigation, monitoring in selected house is part of building performance assessment methods[48]. The methods take account of

- Building description
- Location and site layout
- Building form and internal planning
- Performance assessment, including measurements
- Construction and environmental design

[48] S. Yannas Environmental Assessment Methods, 2001

By means of measurements, data loggers (Hobo, series H8) had been used to monitor in selected environment for a period of 28 days. The aim is to investigate the thermal performance in selected houses. In other words, thermal comfort study is the main objective which consider about the aspects of;

- Influences of microclimate and building designs on thermal comfort level
- Building performance in relation to thermal comfort level in monitored outdoor, indoor environments and air-conditioning performance
- Pattern of air-conditioning use

4.3.2 House selection to be monitored

The selected types of residential buildings are typically found in all regions of Thailand according to the Statistical Yearbook Thailand, 2004[49]; i.e. detached houses, town houses/row houses, high rise accommodation buildings, boats, flooded houses, caravans and others.
In order to decide on a monitored house, assumptions have been made on locations and typical houses with air-conditioning uses. Referring to the earlier study, in the urban areas tend to have a high possibility of air-conditioning use due to hot microclimate and lack of natural wind drives for cooling in buildings. Therefore, the selected monitoring buildings in Bangkok[50] are

- A detached house,
- A town house/row house
- A high rise accommodation building.

4.3.3 Methods of measurements

The three selected houses are to be monitored for 28 days during the rainy season (July to August). In order to make a consistent monitoring, user guides are provided to participants. (Appendix D: a user guide) Clear instructions assist where data loggers are assumably placed in each of selected environment. There are four particular monitored environments which are;

- Outdoor monitoring
- Without air-conditioned room monitoring
- With air-conditioned room monitoring
- Air conditioning unit monitoring

[49] A survey is carried out every 10 years. The latest statistic is in 1996.
[50] Greater Bangkok is included the area of Bangkok, Samut Prakan, Nonthaburi and Pathum Thani.

Chapter 05:

Results and Discussion on Air-Conditioning Use in Thais' Household

5.1 Chapter overview

The purpose of this chapter is to report and discuss the results from the surveys, mainly conducted in the office-workers who work in air-conditioned buildings, and to reveal the data of three selected house monitored. It is divided into two main parts. The first part of this chapter is to examine the air-conditioning use in household of participants who also have a background of air-conditioning use in office. The use of housing air-conditioning analysis also includes three main aspects:

- Relations of building locations, building types and air-conditioned rooms
- Interrelations of AC operation periods, seasons and occupant factors
- Air-conditioning use in relation to energy-saving aspects

The second part is to analyse data in term of building performance assessment. The analysis areas cover:

- Influences of microclimate and building designs on thermal comfort level
- Building performance in relation to dry-bulb temperature and relative humidity in monitored outdoor, indoor environments and air-conditioning performance

At the end of this chapter, relationships between occupants, buildings and air-conditioning use patterns are discussed.

5.2 Survey results and discussion

Air-conditioner acclimatisation background is taken into account the survey. Therefore, the main target groups are participants who are currently working in air-conditioning buildings. Here is the raw data from the surveys: the total subjected surveys were 50 people; 37 females and 13 males. The range of age is found to be 20-54 years. The percentage of house air-conditioning use is 98% of the total subjected surveys.

5.2.1 Relations of building locations, building types and air-conditioned rooms

According to the survey of participants' residential background, there are three typical residential buildings occupied. The dominant residential building is detached house (type01) at 54% of the overall. Row house/ town house (type02) and flat / apartment / condominium (type03) are at 20%and 6% in order. (See figure 5.1) The survey results show that 82% of typical dwellings are located in Bangkok and 12% are scattered in other areas of Greater Bangkok and suburb areas. In addition, this implies that some of participants commute to the work place in the city centre.

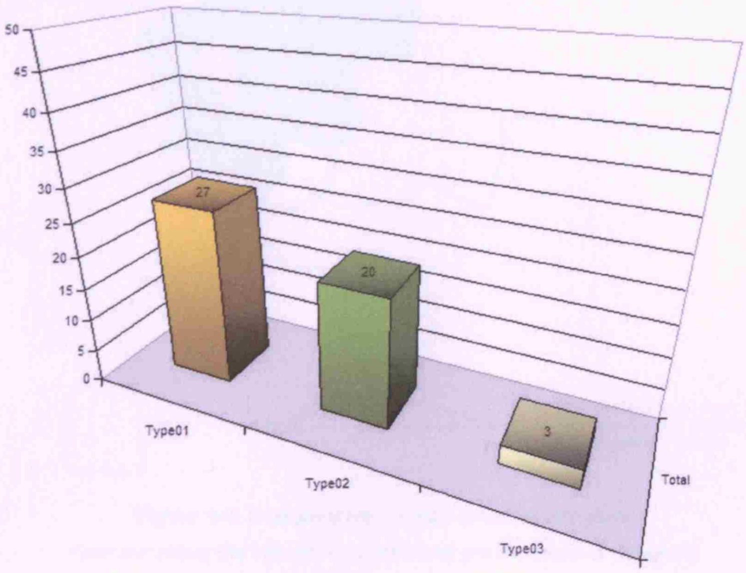

Figure 5.1: the survey of typical residential buildings

(Key: Type01-detached house, type02-Row house/ town house, type03-flat/apartment/condominium)

In order to examine the interrelations of building locations, building types and air-conditioned rooms, contexts of Bangkok land use are essential to be examined. This is on the account of the influences of local microclimate to air-conditioning use.

Bangkok is located at 13°45' Latitude North 97°22' and 100°28' Longitude East[51]. The study of Metropolitan areas of Bangkok[52] has found that spatial system of Bangkok is developed and expanded in four phases. Figure 5.2 presents the spatial system where the first location of capital city is established. Rivers and canals are the main transportation routes. Also, historic areas are used to be the centre of the city and commercial districts. After converting canals into land and expanding new roads in the eastern and southern part of Bangkok.

[51] E. A. Pearce and C. G. Smith, The World Weather Guide, 1993, p.288

[52] A. Kaseamsuk and S. Supsuke, Configuring Network: Changes in Spatial Structures of Bangkok and Local Areas, 2001, p.106-129, Thai document

Extended Areas become a new city and commercial districts as seen in the present day. The second phase continuously expands into the third phase as the city became Greater Areas in which they are occupied as residential districts in the past 15 – 20 years. The last phase is the edge areas where there are land developments going on.

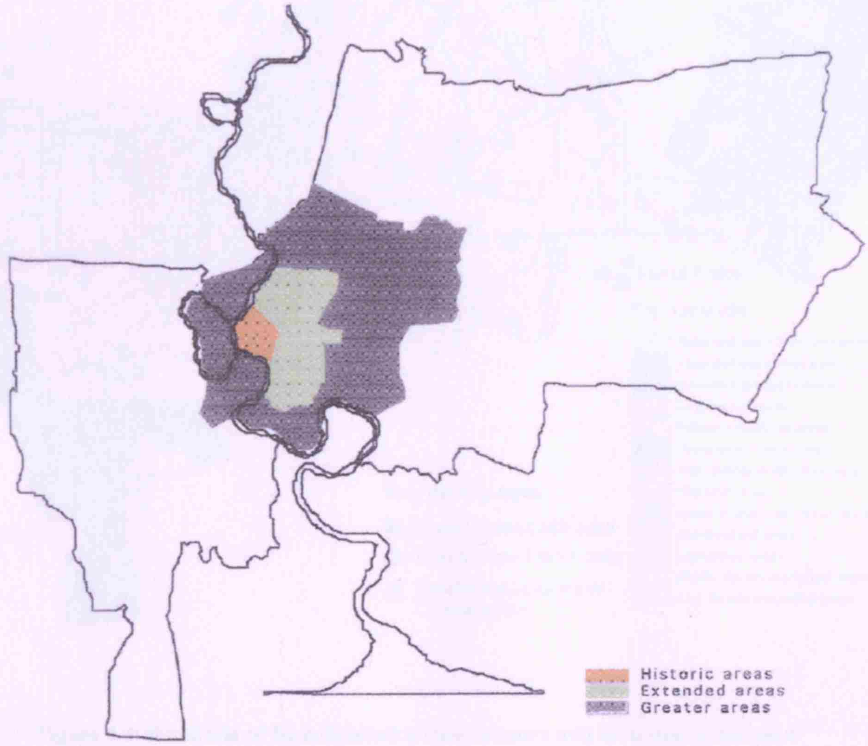

Figure 5.2: Comparative studied areas of Bangkok

(Demonstrating the historic, extended and greater areas of Bangkok)

Overview of the city has a centralized structure where the beginning of settle-down was started from the centre. Thus, high density of land use repetitively appeared in the central zone and less density is found in outer zones. Figure 5.3 demonstrates a combined map of 50 subjected survey houses with the land use in Bangkok.

Density of residential areas is significantly focused in this analysis. By using different colours to show, Brown, Orange and Yellow shaded areas are referred to high, middle and low density, in order. The scattered pattern of three typical buildings explains that there are air-conditioning uses in all levels of land density, though in low density areas while there are high air, noise pollutions and lack of natural ventilation drive in the high density areas. These factors contribute the reason why air-conditioners are used for compromising comfort level of occupants. On the other hand, the areas with less density have the propensity to utilize natural cooling. However, it is too soon to make a conclusion without investigating microclimate and building designs.

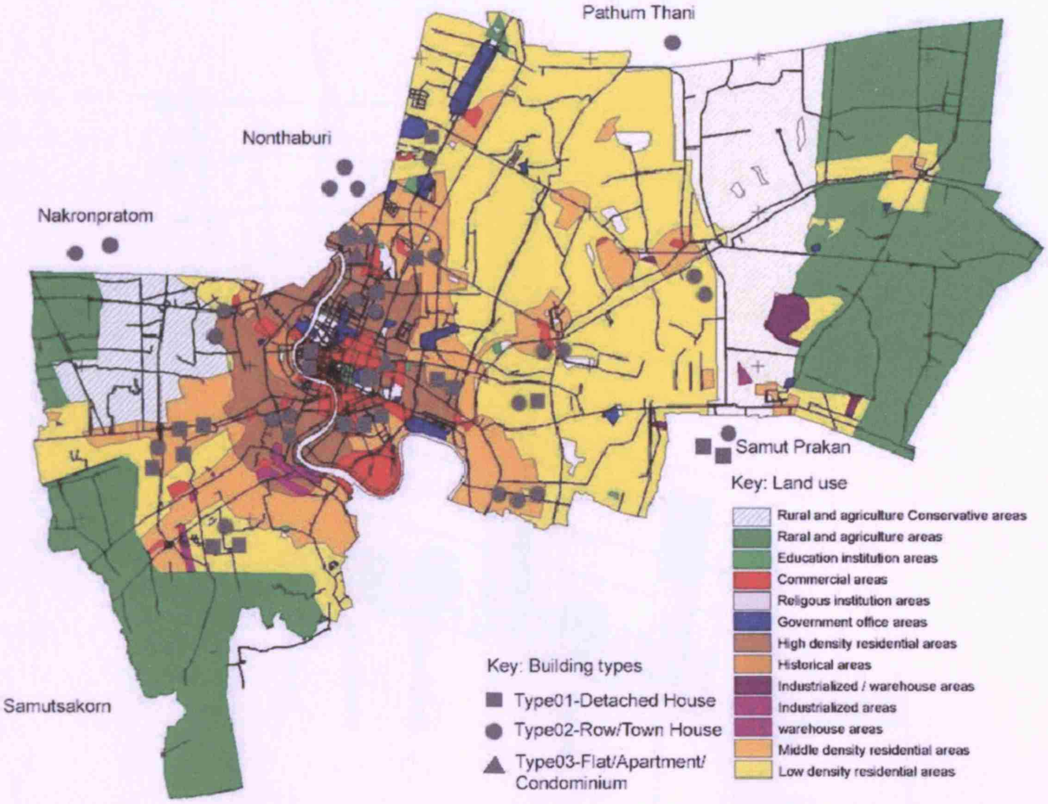

Figure 5.3: Relations of 50 subjected survey houses and land use in Bangkok[53]
(Greater Bangkok covers areas of Bangkok, Nonthaburi, Pathum Thani and Samut Prakan)[54]

The investigation of housing air-conditioning use has found that the dominant air-conditioned room are bedrooms and living rooms respectively in all building types. A typical air-conditioner type is split type system; i.e. wall mounted air-conditioner, ceiling mounted and other types. Air-conditioning uses are also found in other rooms, such as dinning rooms, study rooms, Buddha rooms (meditation rooms) and private rooms. (See figure 5.4) In addition, it appears that the size of family determines numbers of air-conditioning units as demonstrated in table 5.1. That is, for a smaller size of family, it tends to use fewer air-conditioners comparing with a bigger family size. The mean of air-conditioner is 3.1 units per household. However, there are other factors to be taken into consideration; i.e. economic factors, necessities of air-conditioning use and building designs, particularly. For instance, considering the building type, detached houses appear to have a highest average of air-conditioners at 3.5 units per household. Meanwhile row/ town houses and high rise accommodation buildings have averages at 2.9 and 0.7 units per household, as in order.

[53] Bangkok Land Use Regulation, issue of 414, 1999
[54] Key Statistic in Thailand, 2004

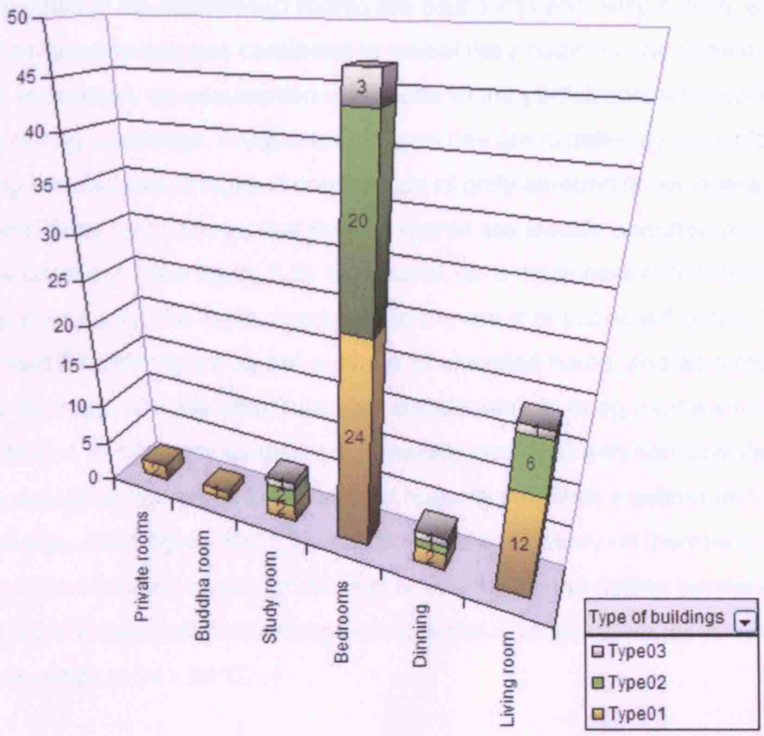

Figure 5.4: Typical air-conditioned rooms in relation to residential buildings

(Key: Type01-detached house, type02-Row house/ town house, type03-flat/apartment/condominium)

		Type of buildings				Average A/C per household
Member	Data	Type01	Type02	Type03	Grand Total	
1	Sum of Number of A/C			1	1	1.0
	Count of Member			1	1	
2	Sum of Number of A/C		1	1	2	0.7
	Count of Member		1	2	3	
3	Sum of Number of A/C	13	4		17	2.8
	Count of Member	4	2		6	
4	Sum of Number of A/C	35	23		58	3.2
	Count of Member	10	8		18	
5	Sum of Number of A/C	17	19		36	3.0
	Count of Member	6	6		12	
6	Sum of Number of A/C	1	8		9	3.0
	Count of Member	1	2		3	
7	Sum of Number of A/C	6	2		8	4.0
	Count of Member	1	1		2	
8	Sum of Number of A/C	16			16	5.3
	Count of Member	3			3	
11	Sum of Number of A/C	4			4	4.0
	Count of Member	1			1	
Total Sum of Number of A/C		92	57	2	151	3.1
Total Count of Member		26	20	3	49	
Average A/C per type of household		3.5	2.9	0.7	3.1	

Table 5.1: Relations of family sizes and building types determine numbers of air-conditioner

5.2.2 Relations of AC operation periods, seasons and occupant factors

As the majority votes of air-conditioned rooms are bedrooms and living rooms, examinations on patterns of air-conditioning use continued to reveal daily patterns and season patterns as demonstrated. In addition, an assumption was made to the participants who work in normal working hours during weekdays. Frequencies in one day are dictated by work lifestyle; in the morning, during the day and at night. A comparison of daily air-conditioner operation between the bedroom and living room shows that the two rooms are usually operated during the day and at night respectively. (See figure 5.5) In general, air-conditioners in bedrooms are commonly operated during the night. According to the result of subjected survey, they are regularly operated for eight hours by the average of operated hours, and air temperature is set at 25 °C by average. On the other hand, air-conditioners in living rooms are operated for various hours from 1 to 10 hours as they are generally occupied with non-specific period time of the day. Six operation hours are found to be a majority vote with a setting air temperature at 25 °C by average. (See figure 5.6, 5.7) According to early study on thermal comfort of the persons who are accustomed to air-conditioned environment, the setting temperatures of both rooms (25 °C) are complied with an average of acceptable temperature for all surveyed regions which is made to 24 - 26 °C.

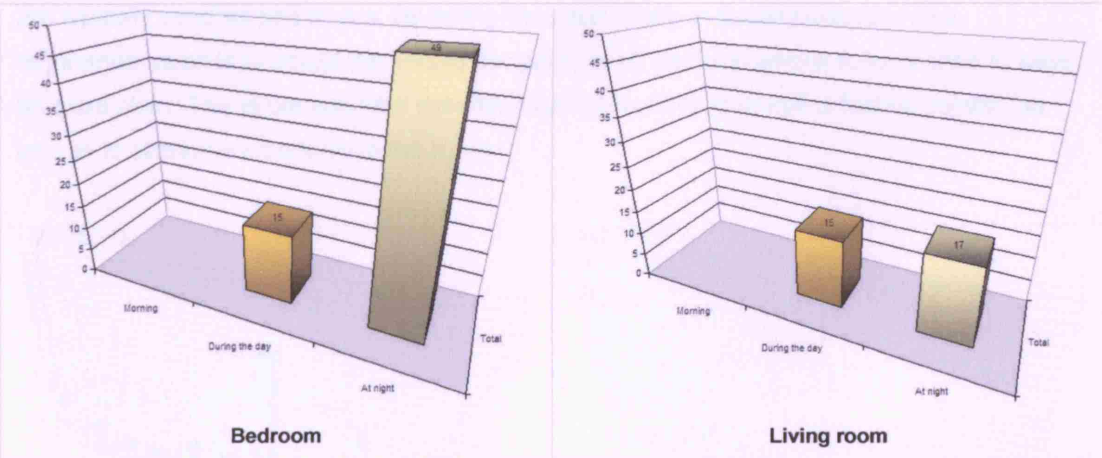

Figure 5.5: Comparison of daily air-conditioner operation between bedroom and living room

Dictating by different seasons, the examination of pattern of air-conditioning use focuses on the scale of operation frequency which can be defined as;

Frequency	Always	Often	Occasional	Rarely	None
Scaled value	2	1	0	-1	-2

Table 5.2: the scale of operation frequency

For the summer use, particularly bedrooms, there are intensive uses of air-conditioners with a scale of 0 to 2. Comparing with the winter use when all scaled values are used, there are some occasions of none air-conditioning use. The trend of below graphs shows that during rainy season, the air-conditioners are still operated with a scale of -1 to 2. (See figure 5.8) Similarly, this pattern use occurs in living rooms during rainy and winter season in which the scales are -1 to 2 and -2 to 2, respectively. In contrast to summer use for bedrooms, there are some occasions of rarely use and less intensive use in living rooms. (See figure 5.9)

The results can be summarised that the patterns of air-conditioning use in bedrooms and living rooms are found that they are usually operated in all seasons. Though, there is some occasion of none air-conditioning use during winter. Regardless of all types of residential building (Type 01, 02 and 03), at night time is always a peak time of air-conditioning operation in typical bedrooms. As far as thermal comfort level is concerned, at the average of eight hours in 25°C air-conditioned bedrooms with metabolic rates of rest activities at 0.9 -1.2 [55]

Moreover, level of clothing is another factor to take into account. The information of clothing level is given out and discovered that there are two main groups of clothing used during air-conditioners are operated. The first group wears a normal clothing level (cloth insulation at 0.2 - 0.27 Clo.[56]in both genders) while the other uses socks and extra jackets. Additionally, duvets are typically used as bed wears. By taking the latter group in to consideration, one recommendation is to adjust the setting temperature to the level where doesn't need to wear an extra cloth. This is because the sensible clothing level is essential to feeling comfort as well as to staying comfortably in the room.

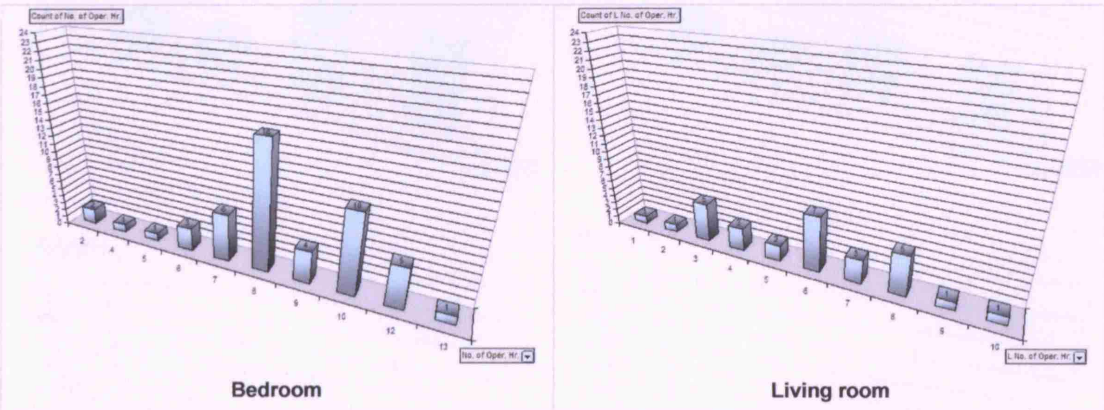

Figure 5.6: Comparison of daily operated hours between bedroom and living room

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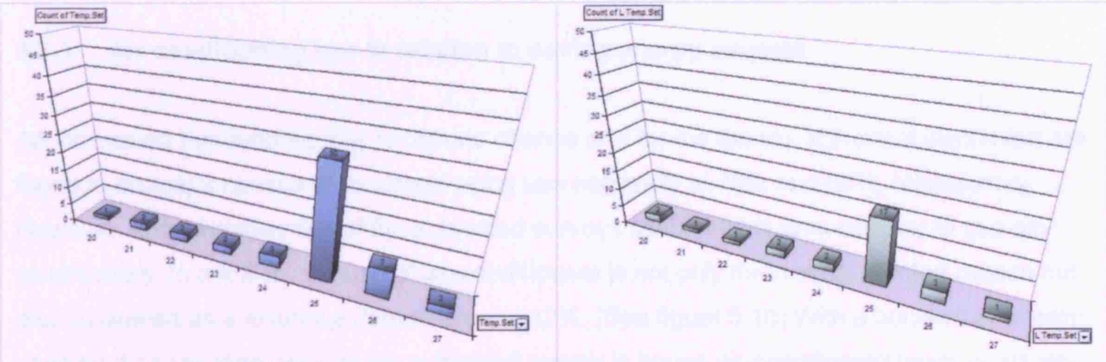
[55] Metabolic rates of rest activities, http://atmos.es.mq.edu.au/~rdedear/pmv/, 2005

"metabolic rates of rest activities: sleeping= 0.9, reclining = 0.8, seated (quite) = 1.0 and standing(relaxed) =1.2" ,

[56] IBID.

Typical clothing garment effective insulation values: Normal wears including T-shirt, short of long straight trousers and men briefs or woman underwear



Bedroom Living room

Figure 5.7: Comparison of setting temperature (°C) between bedroom and living room

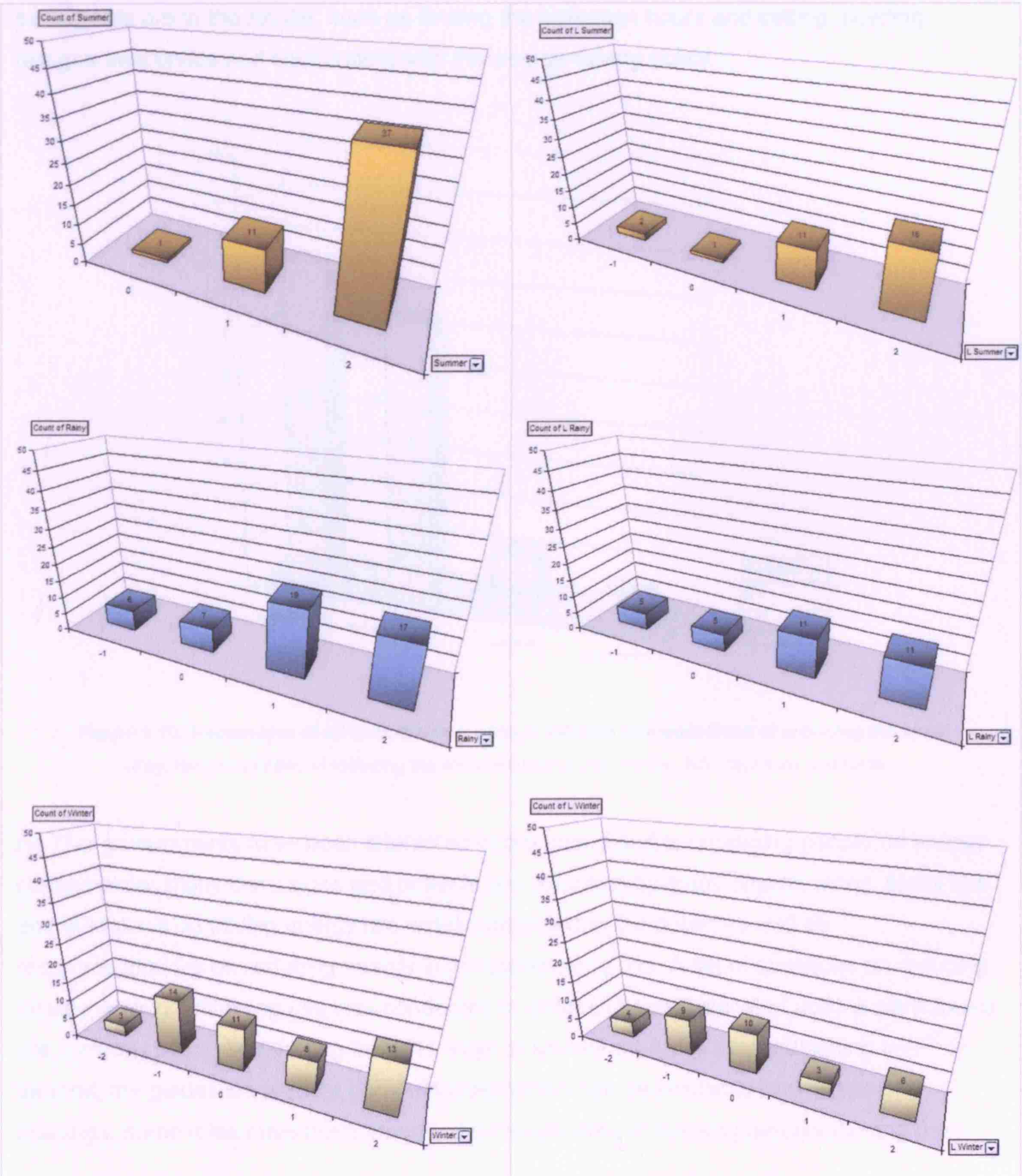


Figure 5.8 (left column): A pattern of air-conditioning operation according to seasons in the bedroom

Figure 5.9 (right column): A pattern of air-conditioning operation according to seasons in the living

(Key: Always = 2, Often = 1, Occasional = 0, Rarely = -1, None = -2)

5.2.3 Air-conditioning use in relation to saving energy aspects

An increasing temperature due to climate change and for the easing of thermal discomfort are found to be major causes of air-conditioning use necessity at 76% and 64%, respectively. However, approximately 6% of the subjected surveys said that it is unnecessary to use air-conditioners. In addition, the use of air-conditioners is not only for thermal comfort reason but also evaluated as a luxurious item at around 12%. (See figure 5.10) With a concern of energy consumption situation, 93% of the subjected survey is house air-conditioning users positively believe that reducing of air-conditioning use is possible. Moreover, the opinions given by participants are in the similar, such as limiting the operation hours and setting, building designs awareness and cooperating with the energy-saving policy.

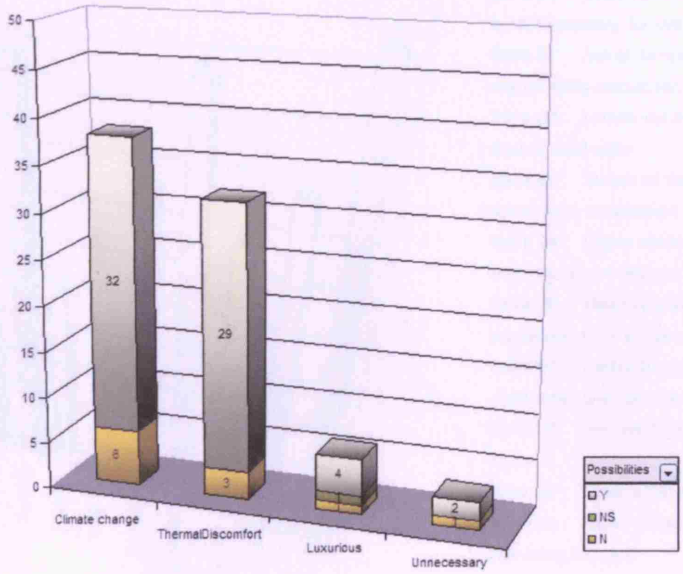
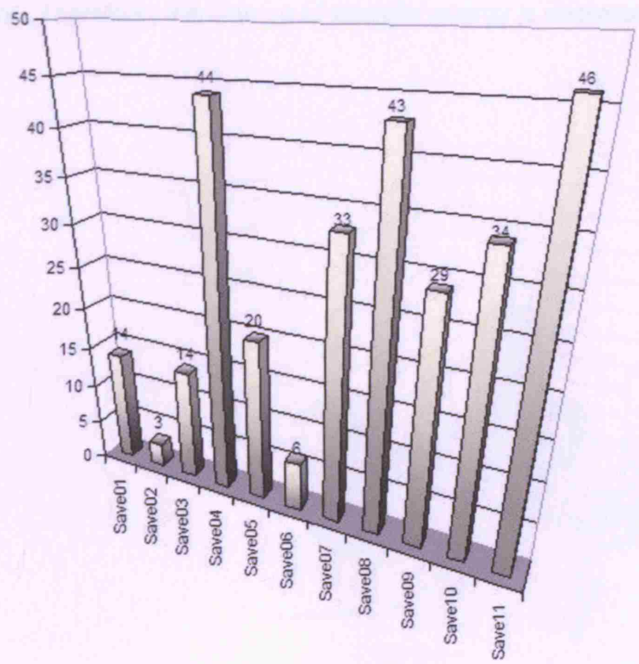


Figure 5.10: Necessities of air-conditioning uses in relation to possibilities of reducing the uses
(Key: the possibilities of reducing the air-conditioning use; Y=Yes, NS= Not sure and N=No)

As Thai governments have been interested in promoting and encouraging people on energy consumption, many campaigns and projects are launched by many organisations. Many tips and guidelines on saving energy are widely promoted to the public as well as recommendations on reducing energy in air-conditioning use. A set of questions on reducing energy in air-conditioning use was conducted in order to investigate what actions participants are currently taking by referring from '11 ways of saving energy in air-conditioning use'[57].In general, the guidelines present general issues which can be practiced in any type of buildings, some rules have been amended corresponding to housing air-conditioning uses.

[57] J. Pavungkarat, Considerations for purchasing air-conditioners, Air-Conditioning Engineering Association of Thailand, 2003,

(Appendix B) The results showed that six out of eleven actions are generally taken; Save 04, 07-11. (See figure 5.11) The results on Save 04, 08 and 11 have majority votes which the taken actions are considered as common rules in air-conditioning users. Also, understanding the ways to eliminate and prevent heat gain as well as an adaptation of clothing level of occupants can reduce cooling load in the room. As seen, Save 07, 09 and 10 are the second majority vote while Save 01-03 and 05-06 are the least majority vote. It is noticeable that actions with specific requirements, such as Save 01-03, have fewer votes than general actions. However, it can be assumed that the guidelines may be not widely acknowledged or practical enough to follow. Moreover, the results of 50 subjected surveys show that there are positive aspects toward saving energy in air-conditioning users.



Save 01 Switch off the ventilation fan when it is not necessary for extra ventilation

Save 02 Set air temperature at 28c and then use an extra electric fan to cool the room

Save 03 Locate wardrobes against either east or west walls

Save 04 Switch off the air-conditioner when the room is unoccupied

Save 05 Leave windows and doors shut while the air-conditioner is not operated

Save 06 Remove unnecessary electric appliances from the air-conditioned room

Save 07 Switch/turn off unused electric appliances and lightings

Save 08 Not smoke in the air conditioned room

Save 09 Wear a thin cloth level

Save 10 Close curtains or blinds while operating A/C unit

Save 11 Windows and doors are shut properly

Figure 5.11: Relations of 50 subjected survey houses and land use in Bangkok

To rely on cooling technology for cooling purpose, one needs to be aware not only to know how to operate but rather know how to use it sensibly. For instance, in hot humid climate conditions, it is often that there is a situation of high air temperature and dampness occurred. It is often overlooked that the amount of wasteful energy from cooling load is produced when an air-conditioner is operated in a high temperature room. Therefore, methods of cooling the room are certainly affected on energy consumption. The survey examines how participants cope with the situation when hot air temperature occurred in the air-conditioned room. The results reveal that pre-cooling the room before operating the air-conditioner by opening windows or doors is the most preferred method. (See figure 5.12) Not to mention that relying on natural ventilation is an advantage method which is a free cooling. However, for some participants, turning on an air-conditioner promptly is chosen as the most preferred cooling method. Since work load on air-conditioners and wasteful energy is concerned, cooling air by operating electric fan is accepted as the second preferred method with a majority vote.

Though electric fans are commonly used in households before being accustomed to air-conditioner use, it is widely accepted as an affordable cooling technology. Moreover, the use of electric fan increases air velocity in the room with a speed of 1.5 m/sec[58] which can make occupants feel comfort and also increases the air exchange rate which can help creating ventilation in the room. Air-conditioning use is chosen as the third preferred cooling method. In addition, some participants suggest the use of curtain to help cooling the room. The overall results show that the trend of cooling the room is logically operated via utilising the natural ventilation for the first step and then operating the electric fan before turning air-conditioning on. Therefore, the amount of wasteful energy is decreased by means of pre-cooling the air.

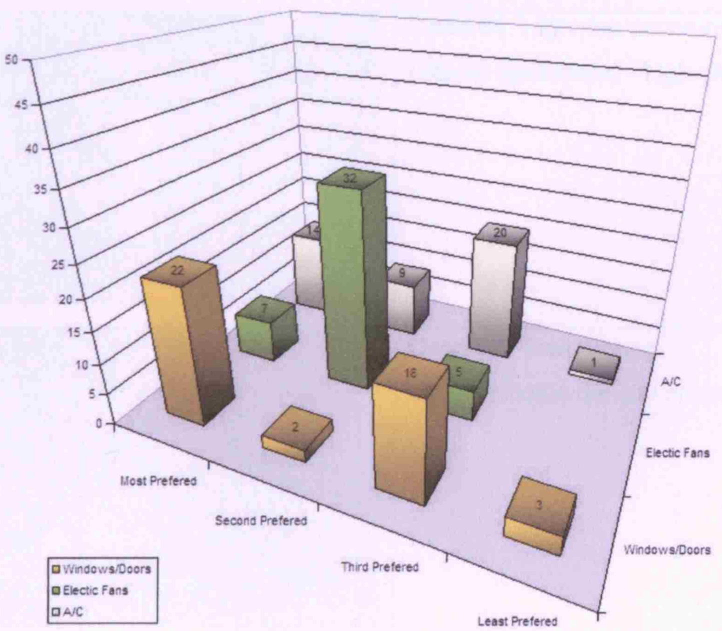


Figure 5.12: A rank of cooling methods

[58] M. Srisuwan, The study of Air Flow Patterns in Relation to Building Wall Openings for Tropical Climate of Thailand, 2000, P.14

5.3 Measurement results and discussion

As the results of survey reveal that air-conditioners are operated all year round. It becomes a crucial issue of what main factors causing intensive uses are. Some occupants prefer to stay cool and comfortable. However, building designs should be critically taken into account. In order to see the situation clearer, the measurement results of three selected houses are revealed with an aspect of building performance assessment.

5.3.1 Influences of microclimate and building designs on thermal comfort level

An assumption in relation to urban contexts, where there are varieties of density was made when selecting the monitored houses. It is assumed that the density can be the key necessity in air-conditioning use; as clarified in table 5.3

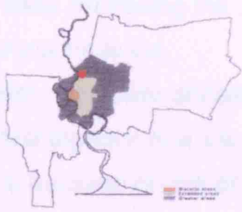
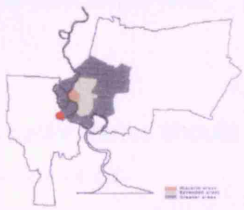
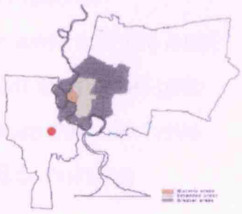
Density of land use	Location
	**Case 01**: High rise accommodations (Studio apartment) - high density of land use 
	**Case 02**: Town house high to middle density of land use 
	**Case 03**: Detached house middle to low density of land use 

Table 5.3: Relations of density of land use and open spaces[59]

[59] Image source, Google Earth, 2005

Regarding bioclimatic building designs, the orientation of building is essential in order to take advantage of prevailing winds for natural ventilation as important as to reduce the amount of solar radiation on the building envelope. Density of land use seems to be a limitation of building envelope designs and affects to microclimate. According to weather stations; Bangkok Metropolis weather station (100° 34 E, 13 ° 44 N) and Don Muang Airport weather station (100 ° 36 E, 13 ° 54 N), it can be described that the outer areas of city, air temperature is found to be hot and humid during rainy and summer than in the central. Cloudiness[60] is found to be partly cloudy to cloudy in all seasons. While in winter, in the central, it is found to have higher temperature and dry with lower humidity, which can be recognised as a heat island phenomenon. (See table 5.5)

Although, the measurements were taken in rainy seasons (July to August), the hot microclimate is found that the area of case 01 and 02, are situated near the city centre, have higher average temperature than case 03. (See figure 5.13, 5.14) There are two major explanations to high temperature conditions that can be realistically made. First, existing buildings and lack of wind drive due to obstructions from other existing buildings act as a thermal mass in the area. As for the case of the high rise building (case01), being at the higher levels enables us to utilise natural ventilation as the cool air take-away exceeding the heat. Whereas, for the low rise in dense land (case 02), it has more obstructions at the ground level, as well as undesirable indoor temperature occurring. In addition, in lower dense (case 03), it is found that the site with more surrounded open areas is advantageous to a low temperature as influenced by cool microclimates. The other explanation is because of lack of vegetations or green space, as table 5.4, aerial photos illustrate the proportion of landscape areas (green spaces) in relation to land density. Since high air temperature affects indoor temperature. Hence, building envelope designs are essential to reduce the amount of heat gain into the building.

As building envelopes are regarded as our third skin, a satisfied building performance should go hand in hand with the requirement of thermal comfort level. An awareness of air-conditioner use with energy consumption concerns has been discussed. A research of the design for low energy house [61] states that the main factor of work load on cooling is caused from two main factors. Direct and indirect solar radiation roof where its surface of conductance has occurred for long hours. Façades face in the south, the west and the east also receive the solar radiation on the building surface. As far as these two main heat gain factors are concerned, internal planning is essential to take a critical look as this can have significant effects on indoor thermal comfort level. As illustrated in table 5.5, building

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[60] http://www.dnr.state.sc.us/water/climate/sercc/climateinfo/historical/avgcldy.html, 2005

"The mean numbers of days per category of cloudiness as the categories are determined for daylight hours only. Clear (CL) denotes zero to 3/10 average sky cover. Partly cloudy (PC) denotes 4/10 to 7/10 average sky cover. Cloudy (CD) denotes 8/10 to 10/10 average sky cover".

[61] O. Panin, The design for low energy house, 1983, Thai document

descriptions are given and discussed about the internal layout in the monitored buildings

	Dry bulb temperature (C)		Relative humidity (%)		Cloudiness	
	BKK Metropolis	Don Muang Airport	BKK Metropolis	Don Muang Airport	BKK Metropolis	Don Muang Airport
January	27.8	27.5	68	75	5	4
Febuary	27.9	27.7	72	74	5	4
March	30.2	30.3	72	70	5	4
April	**31.2**	**31.7**	69	72	5	4
May	30.0	30.0	74	79	7	6
June	29.4	29.5	75	80	8	6
July	29.7	30.2	71	79	8	6
August	29.1	29.5	74	80	**9**	**7**
September	28.9	28.9	**76**	**84**	8	6
October	29.8	29.3	65	73	7	5
Noverber	29.9	29.4	60	66	5	4
December	27.3	26.9	56	60	4	3

Table 5.4: The summary of weather data in 2004[62]

(Key: Orange, Blue, Grey shades are represented as summer, rainy and winter seasons, respectively)

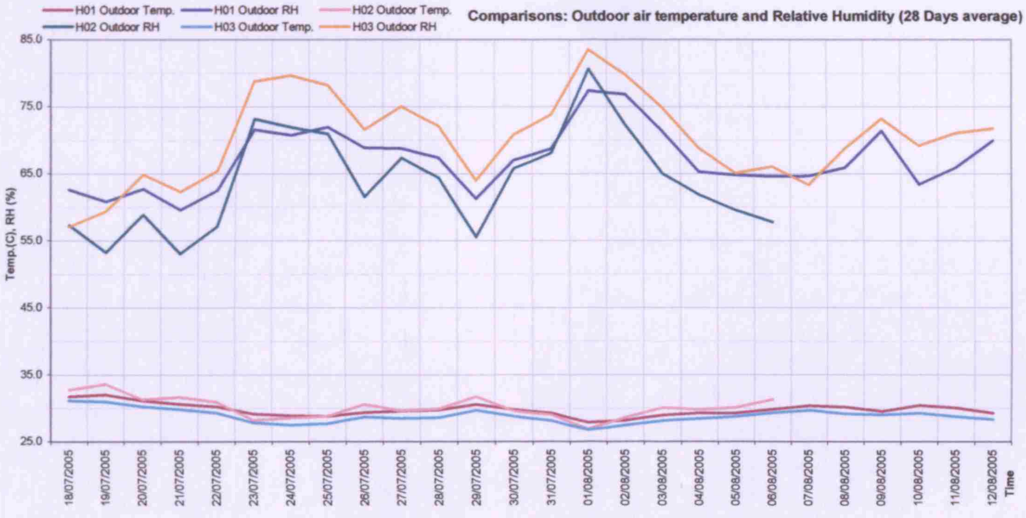

Figure 5.13: Comparisons of outdoor air temperature and relative humidity of monitored houses, 28 days average[63]

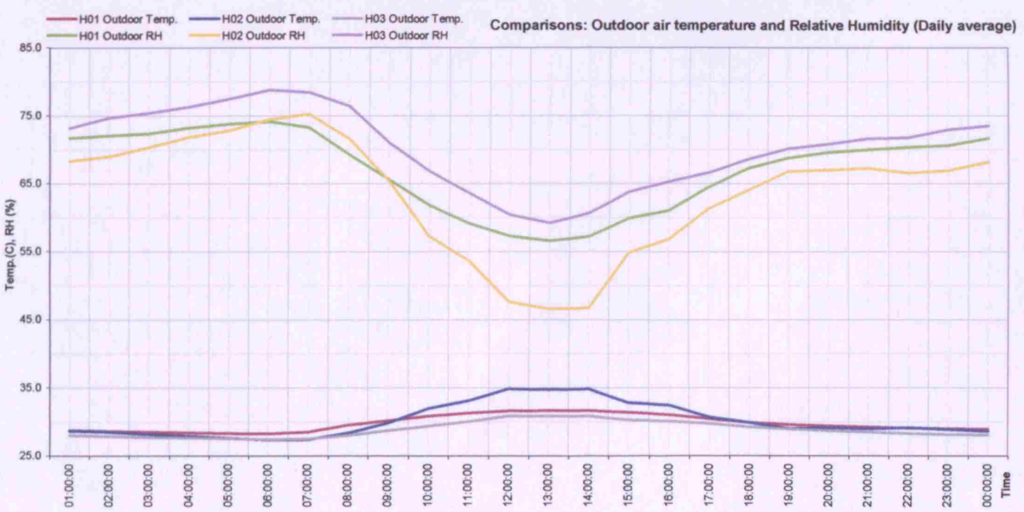

Figure 5.14: Comparisons of outdoor air temperature and relative humidity of monitored houses, hour average

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[62] Thai Met Office, 2004, http://www.tmd.go.th/index.php

[63] Note: Data weather of house 02 is stopped on 06 August 2005, due to errors in the data logger

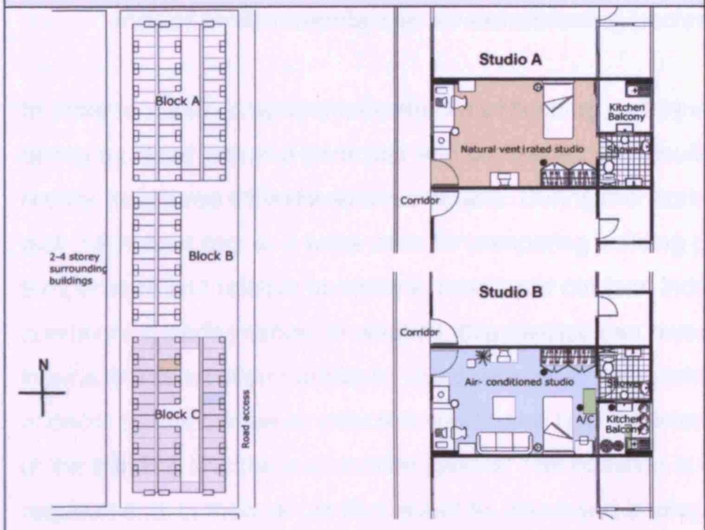
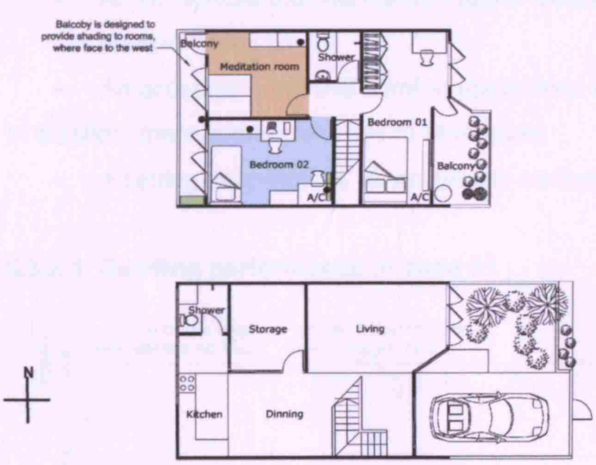
Building envelope designs and internal planning	Building descriptions
 **Case 01: High rise accommodation building – studio apartments**	Three blocks of 15-storey apartment buildings are situated slightly off from the city centre. The building form is simply designed in box shapes with no shading feature in order to create as many as possible of living units. The long axis of buildings faces east and west without provided solar shading. Two studio apartments on 13th level were monitored as natural ventilated and air-conditioned studio apartments. The internal planning consists of living space, shower room and open air kitchen.
 **Case 02: Town house**	A block of two-storey town house is situated slightly off from the city centre. The building form is simply designed in a row of building where consists of 15 blocks. The long axis of buildings faces east and west. Balcony on the west side provides shading to the rooms where two monitored rooms are located, on the first floor. The main construction is concrete with rendered brick wall for building envelope A non-insulated roof is constructed with a tilted angle for drainage.
 **Case 03: Detached house**	A three-storey detached house, including basement, is situated off from the city centre where has green space surrounded in the area. The building form is designed to have western feature. The orientation of the building is slightly tilted to northeast and southwest. Two monitored rooms are located on the first floor where both side of the building install overhangs for sun protection. The main construction is concrete with rendered brick wall for building envelope. A pitch roof without insulation is constructed.

Table 5.5: Building envelope designs and internal planning

(Key colour: Orange = Natural ventilated rooms, Blue = Air-conditioned rooms)

5.3.2 Building performance in relation to thermal comfort level in monitored outdoor, indoor environments and air-conditioning performance

In order to make comprehensive results of building performance in three monitored cases, taking a critical look at a particular and comparing the results are the ways to examine the results from three different sources of data. During monitoring period, it is a pre-decision to pick the hottest day as a base case for comparing building performance in relation to dry-bulb temperature and relative humidity in monitored outdoor, indoor environments and air-conditioning performance. In addition, this method can reveal how well the buildings perform in an extreme weather condition. The data analysis also takes thermal comfort analysis into account as this can be an effective way to see how the interaction between the performance of the building and thermal comfort level is. The question is do the buildings achieve the requirements in thermal comfort level? As discussed in chapter 02 on thermal comfort, therefore, there are keys set to keep in mind;

- An acceptable thermal comfort upper level in natural ventilated buildings at approximately 31 ^{o}C
- An acceptable thermal comfort upper level in air-conditioned buildings at 26 ^{o}C.

In addition, there is one extra key to determine;

- A setting temperature, as occupants claimed, at 25^{o}C in all monitored cases.

5.3.2.1 Building performance in case 01

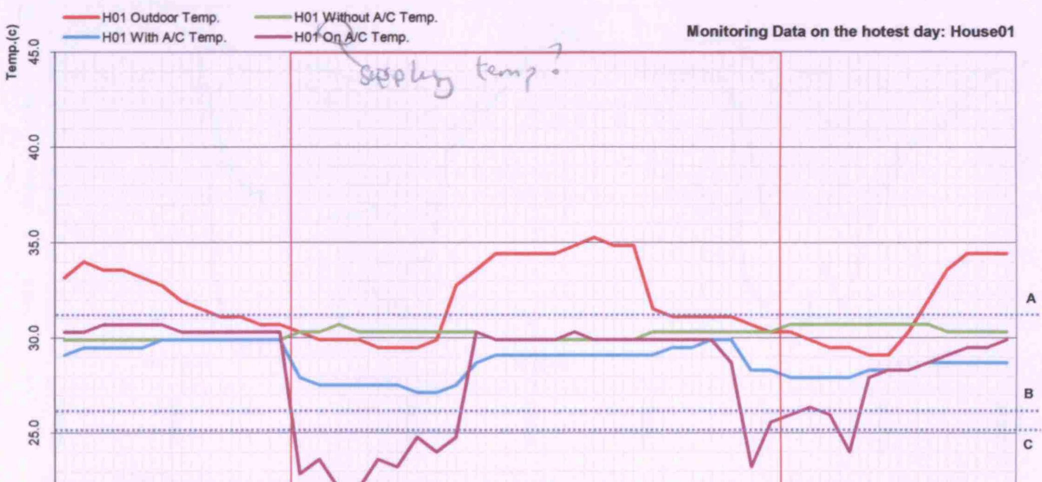


Figure 5.15: Comparisons of air temperature and thermal comfort level on the hottest day - Case 01

(Key: Level A = thermal comfort in natural ventilated buildings at approximately 31 ^{o}C, Level B = thermal comfort air-conditioned buildings at 26 ^{o}C and Level C is a setting temperature at 25^{o}C)

The building performance in studio A and B has found that the thermal mass of the room can capable to the high temperature which occurs during the day at approximately 30 °C is the average of internal air temperature which achieves the level of thermal comfort in natural ventilated environment. Analysis of internal planning in studio A and B finds that kitchen/balcony area and shower room are designed to be a buffer zone for which is the reason. However, in the humid day, the internal room temperature is high as a consequence of the buffer zone obstructs the natural ventilation which causes less air movement. As in the early study of traditional Thai house, by orientating kitchen area to the west for shading the living space and utilising solar radiant for pasteurise the damp area. The same principle is applied in the modern building. However, the occupant in studio B still operated the air-conditioner. The data reveal that actual cold air temperature did not reach as the setting temperature of air-conditioner was claimed to set at 25°C.

5.3.2.2 Building performance in case 02

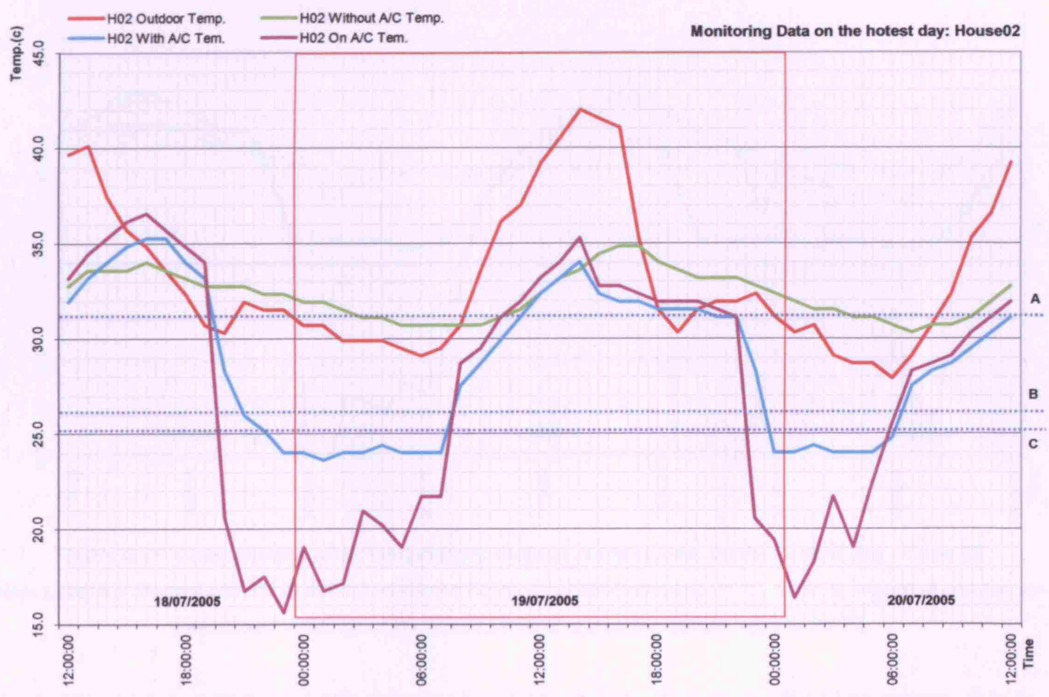


Figure 5.16: Comparisons of air temperature thermal comfort level on the hottest day - Case 02

(Key: Level A = thermal comfort in natural ventilated buildings at approximately 31 °C, Level B = thermal comfort air-conditioned buildings at 26 °C and Level C is a setting temperature at 25 °C)

Due to west orientation of the two monitored room, high temperature on the west side always occurs, especially peak time of the day. For this reason, a balcony is designed to provide shading on both rooms. However, the building performance has found that the room can not achieves the level of thermal comfort in natural ventilated environment and often store the heat during the night due to lack of ventilation. Considering the location of the rooms where are located on the top floor, roof system has directly affected on internal heat gain. Without insulation in the roof, there is only a plaster broad ceiling layer working as roof insulation. Consequently, amount of energy for cooling load is wasted. According to the trend of air-conditioner performance, it has found that extra cooling load was produced to keep up the setting temperature room. The cold air temperature from the air-conditioner was found at approximately 16°C from the peak cooling load where the mixed air temperature was achieved at the average of 24°C.

5.3.2.3 Building performance in case 03

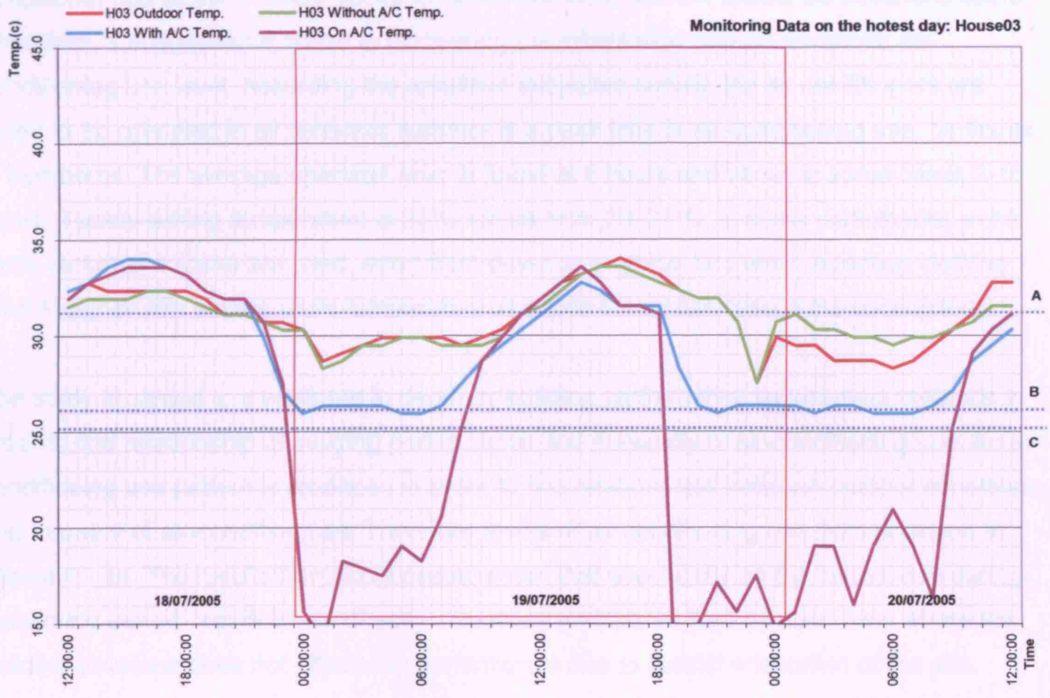


Figure 5.17: Comparisons of air temperature thermal comfort level on the hottest day - Case 03

(Key: Level A = thermal comfort in natural ventilated buildings at approximately 31 °C, Level B = thermal comfort air-conditioned buildings at 26 °C and Level C is a setting temperature at 25 °C)

The house was assumed to have a better building performance than other two cases, due to the area context has cool microclimate. In contrast, the building envelope does not performance well as the internal air temperature level is not much different from outdoor temperature level. In the other words, the internal conditions pretty much depend on the weather conditions. Massive cooling load in air-conditioned room was produced to keep up the setting temperature room where it achieved at the average of 26°C.

5.4 Discussion and conclusions

Due to the causes of high temperature and climate change effects are mainly the reason for the air-conditioning use. In some aspect, air-conditioners are evaluated as a luxurious item than only used for cooling. Though, the attitudes in participants towards energy consumption are relatively optimistic about reducing energy use and found interested in taking actions on reducing air-conditioning use by following 11 ways of saving energy in air-conditioner users. The general aspects on operating air-conditioners are typically considered; turn off the air-conditioner when the room is occupied and close the doors and windows properly. Whereas, the rules with more specific recommendations are found less to be taken into actions; i.e. orientate the furniture against the walls on west and east and setting higher temperature at 28°C and then operate electric fan to increase air movement in the room. Since air-conditioner use exists in Thais' social for sometime now, we now should be advanced users. Therefore, a suggestion is made to pioneering the information with an advanced air-conditioning use level. According the results of subjected survey, the air conditioners are found to be operated in all seasons; summer is a peak time of air-conditioning use, particular in bedrooms. The average operated hour is found at 8 hours and varies in some cases 2-13 hours. Typical setting temperature is 25°C varies from 20–27°C. In some participants, extra cloth; jacket and socks are used, apart from duvet as a typical bed wear. Adapting clothing level together with set the room temperature at comfort level can reduce the cooling load.

The study is carried to investigate in depth by building performance assessment methods in order to find relationship of building performance and necessity of air-conditioning use. An air-conditioning use pattern is produced in order to find relationships between outdoor conditions and frequent of air-condition use. There are levels of air-conditioning use from occasion to intensive use. The results from three cases reveal that specifically on the hottest day during monitoring period, microclimate directly influences on internal thermal conditions where the building envelope does not effectively performance due to restrict orientation of the site, internal planning and construction material basics, particularly in case 01 and 02. In case 03 is found to have a better thermal mass as occupants can stay in a comfort zone (natural ventilated room condition). However, there are most of the time that air-conditioner was operated. In summary, the necessity of air-conditioning use has been caused by the high-temperature where poor performance of building is influenced by hot microclimate.

Day (s)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	
		31.8	32.0	31.2	30.6	30.3	29.2	28.9	28.8	29.4	29.6	29.7	30.6	29.8	29.3	27.9	28.2	29.0	29.3	29.3	29.9	30.3	30.2	29.5	30.4	30.0	29.3		Temp.(C)
House01		62.6	60.8	62.7	59.6	62.5	71.6	70.8	71.9	68.9	68.8	67.3	61.3	67.0	68.7	77.3	76.8	71.4	65.3	64.8	64.6	64.6	65.9	71.4	63.4	65.9	69.9		RH.(%)
		32.7	33.6	31.3	31.7	30.9	28.2	28.5	28.8	30.5	29.6	29.9	31.7	29.6	29.0	28.9	28.6	30.1	29.8	30.1	31.3								Temp.(C)
House02		57.3	53.2	58.9	53.0	57.1	73.1	71.9	70.9	61.5	67.3	64.3	55.5	65.7	68.0	80.6	72.3	65.0	61.8	59.5	57.8								RH.(%)
		31.1	31.0	30.2	29.8	29.3	27.9	27.5	27.7	28.7	28.5	28.6	29.7	28.8	28.1	26.8	27.4	28.2	28.5	28.8	29.3	29.7	29.2	29.0	29.3	28.8	28.3		Temp.(C)
House03		57.1	59.4	64.8	62.3	65.4	78.7	79.6	78.2	71.6	75.0	72.1	63.9	70.8	73.8	83.5	79.8	74.9	68.8	65.0	66.1	63.4	68.8	73.2	69.2	71.1	71.7		RH.(%)

Table 5.6: Comparison of air-conditioning use pattern in relation to outdoor air temperature and relative humidity during 28 days of monitoring[64]

[64] Note: On case or, missing data due to errors in data loggers. The frequent of air-condition use is confirmed by participants when there were operations in full period of monitoring.

Chapter 6: Conclusions

Living with the cooling technology, effects do not only directly on energy consumption but on climate, people and buildings. After 'Cooth' cult is accepted in Thai's societies, there have been major transformations in Thai life style as well as in Thai architecture. People have become more accustom to air-conditioned environment, where stating point was original from office and commercial buildings. Air-conditioner acclimatisation behaviour has started to grow in Thai's, particular in urban cites. Bangkok is the case to study. According to the results of subjected survey reveal that air-conditioners are operated all year round. It becomes a critical issue of what is the factor of intensive uses. Is it because people who become more accustom to air-conditioned environment and demand to stay in cool environment or high temperature due to climate change effects? The survey was conducted with a purpose for investigating the relations of building locations, building types and air-conditioned rooms. It occurs that in typical residential buildings commonly employ air-conditioners for cooling, where are generally found in bedrooms and living areas. Base case in Bangkok, an average of air- conditioner per household is 3.1 units. The investigation was extended to examine operation periods of air-conditioning in relation to influences of seasons as summer is considered to a peak time when there are intensive air-conditioning uses. Air temperature setting is majority voted at 25°C and 8 hours by average of operation period. As discussed that the traditional three way interaction between climate, people and buildings as one affect one another. Buildings can be a possible factor of necessity in air-conditioning use. The measurements were taken in three typical type of residential building; a detached house, a town house and a high rise accommodation building. In order to make a comprehensive study, the analysis is included the aspects of influences of microclimate and building designs on thermal comfort level. The results reveal that the capable of thermal resistant in building envelope is found to have a poor performance as it does not meet the requirements of thermal comfort level, base case of monitored detached house and townhouse. This can be a piece of evidence that the necessity of air-condition use causes from the building design. However, there is a positive sign from participants who have intentions to reducing air-conditioning with a concern of energy consumption. A suggestion is made to improvements of building envelope of existing buildings in order to improve the building performance as this can lead to a further study. Furthermore, in a new building design is recommended to include an aspect of low energy cooling of building strategy. By applying the strategy of bioclimatic building design, regarding to traditional Thai dwelling design, can be another effective way to create a friend building to environment and occupants with less reply on air-conditioner.

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Appendices

Appendix A: Overview of Thailand

Appendix B: An example of questionnaire form

Appendix C: "11 ways to save air-conditioners costs"

Appendix D: A user guide

Appendix E: Building performance assessment: measurement results

Appendix A: Overview of Thailand[65]

COUNTRY OVERVIEW	
Geography	Maximum Length 1,620 km. Maximum Width 775 km. Land Area 513,115 sq.km. (Equivalent to the size of France, or slightly smaller than Texas)
Climate	Tropical monsoon climate with a high degree of humidity Annual average temperature 22.5°C - 32.3°C Rainy season (May to October) 24.1°C - 31.8°C Cool season (November to February) 20.3°C - 30.8°C Hot season (March to April) 23.2°C - 34.2°C
Population	64 million (8 million in Bangkok)
Religion	Buddhism 94% Islam 4% Christianity 1% Others 1%
Literacy	(% of population age 15 and above) Male 97.10% Female 93.90%
Currency	Baht (41.50 Baht/US$ - 2003 average rate)
Language	Thai
Government	Constitutional Monarchy Head of State King Bhumibol Adulyadej Head of Government Prime Minister Thaksin Shinawatra The parliament comprises 200 elected Members of the Senate and 500 elected Members of the House of Representatives
GDP	3,669 billion baht (6.1% growth from 2003)
ENERGY OVERVIEW IN 2004*	
Total Primary Energy Supply	83,155 ktoe
Per Captita	1.3 toe
Final Energy Consumption	52,431 ktoe (9.6% growth from 2003)
Proven Crude Reserves	291 million barrel
Crude Oil Production	85,750 bbl/d
Net Crude Oil Imports	815,806 bbl/d
Condensate Production	68,390 bbl/d
Oil Refining Capacity	1,022,000 bbl/d
Petroleum Products Consumption	717,975 bbl/d
Proven Natural Gas Reserves	14,754 thousand million cubic feet
Natural Gas Production	domestic 2,163 mmscfd, Import (from Myanmar) 729 mmscfd
Natural Gas Consumption	2,892 mmscfd
Coal Reserves	2,140 million tons
Coal Production	domestic 20 million tons, import 7.5 million tons
Coal Consumption	27.5 million tons
Electric Generation Capacity	26,056 MW
Electricity Generation	127,511 GWh
Electricity Consumption	113,979 GWh
Peak Demand	19,326 MW

* Excluded Renewable Energy Primary source: Bank of Thailand, DMF and EPPO

[65]Energy Information System Development Division, EPPO, 2005

Appendix B: An example of questionnaire form

Air Conditioning use in Thai Household Survey 2005

This questionnaire forms part of dissertation carried out by MSc student on the Environmental Design and Engineering Course at the Bartlett Graduate School of UCL, it has not been requested by UCL. The aim of the questionnaire is to collect primary data in air conditioning use in Thai households.Please help by filling or ticking in this questionnaire as accurately as possible.If you have any comments that you feel are relevant to the study please write on the back of the sheet. The collected data is anonymous and cannot be traced back to you.

UCL

1 **Please state your gender and age**

Male	Female	Age of ....

2 **Please locate the current residential area** (postcode) ☐

3 **Please state how many members are in the household** ☐

4 **Please state the type of your residential building**

Detached house	Row house	Town house
Flat / Apartment / Condominium		Others ....

5 **Please state how many storeys in the building** ☐

Where the case you are living in a **flat / apartment / condominium**, please state which floor of you unit is located ☐

6 **Please give details of air conditioning use in the household**

(In case where there is non air conditioned room in the building, please continue the survey on **question 9**.)

In total number of **A/C*** units	

(In case there are air conditioned rooms more than one, please continue give the details in the tables as provided on back of the sheet.)

Operated in room			
Usual period of A/C operation	Morning	During the day	At night
Average numbers of operation hours			
Type of A/C unit	Wall mounted	Ceiling Mounted	others.......
A/C system setting	Auto setting	Individual setting	
Timer mode setting	Always	Sometimes	Never

Please state the temperature when A/C unit is operated ☐ °C

Please give details of how frequent of use the air conditioning unit

Seasonal	Frequent of Operating A/C units				
Summer	Always	Often	Occasional	Rarely	None
Rainy	Always	Often	Occasional	Rarely	None
Winter	Always	Often	Occasional	Rarely	None

7 **Please state the level of clothing when A/C unit is opertated**

☐

8 **Please select what actions you have been taking** (select more than one action)

- ☐ Swich off the ventilation fan when it is not necessary for extra ventilation
- ☐ Setting air temperature at 28c and then use an extra electric fan to cool the room
- ☐ Locate wardrobes against either east or west walls
- ☐ Swicth off the A/C unit when the room is unoccupied
- ☐ Leave windows and doors shut while the A/C unit is not operated
- ☐ Remove unnecessary electric appliances from the air conditioned room
- ☐ Switch/turn off unused electric appliances and lightings
- ☐ Not smoke in the air conditioned room
- ☐ wearing a thin cloth level
- ☐ Close curtains or blinds while operating A/C unit
- ☐ Windows and doors are shut properly

9 In a situation of high air temperature in the room. Please rate methods of cooling the air temperature before A/C unit is operated. By ranking from the most prefred method(1) to the least prefered (4)

Open windows/ doors	Turn on an electric fan	Turn on A/C straight away	Orthers....

10 What is your option on a necessity of air conditioning use on these days? select more than one

Ease thermal discomfort	Higher temperature due to climate chage	A luxurious item	Others...............

11 Currently, we are facing the situation of fuel consumption. Is there any possibilities of reducing the A/C use in your household? Please give the reason of the dicision.

yes	**no**	**not sure**	**reasons**

Note: A/C units = Air conditioning units

THANK YOU FOR YOUR TIME, please write any additional comments on the back of this sheet.

(CONTINUE) Question 6 Please give details of air conditioning use in the household.

Operated in rooms			
Usual period of A/C operation	Morning	During the day	At night
Average numbers of operation hours			
Type of A/C units	Wall mounted	Ceiling Mounted	others.......
A/C system setting	Auto setting	Individual setting	
Timer mode setting	Always	Sometimes	Never

Please state the temperature when A/C unit is operated °C

Please give details of how frequent of use the air conditioning unit

Seasonal	Frequent of Operating A/C units				
Summer	Always	Often	Occasional	Rarely	None
Rainy	Always	Often	Occasional	Rarely	None
Winter	Always	Often	Occasional	Rarely	None

Operated in rooms			
Usual period of A/C operation	Morning	During the day	At night
Average numbers of operation hours			
Type of A/C units	Wall mounted	Ceiling Mounted	others.......
A/C system setting	Auto setting	Individual setting	
Timer mode setting	Always	Sometimes	Never

Please state the temperature when A/C unit is operated °C

Please give details of how frequent of use the air conditioning unit

Seasonal	Frequent of Operating A/C units				
Summer	Always	Often	Occasional	Rarely	None
Rainy	Always	Often	Occastional	Rarely	None
Winter	Always	Often	Occasional	Rarely	None

Additional comments

Appendix C: "11 ways to save air-conditioners costs"[66]

1. Turn off the ventilated fans when off use

The ventilated fans might be necessary in some rooms where they are full of smoke or smell in order to create ventilation in the room. However, when the ventilated fans work for long hours, the air-conditioners will work even harder to cool the air coming through ventilated fans.

2. Turn off the computer monitor after use and always set stand-by mode

Usually one PC release heat about 250 watts and out of this amount about 180-200 watts is coming from the monitor. Therefore, always setting the stand-by mode on your computer will help reduce the heat from it.

3. Set your air-conditioners at 28° C together with an electric fan use.

There are 3 main factors contributing to thermal comfort; which are,

1. Temperature
2. Relative humidity
3. Wind velocity/speed

To maintain the level of thermal comfort, you can adjust one factor to replace another factor. For example, normally if you would like to cool the room and save the air-condition costs at the same time, you have to set the temperature at 25° C-26° C. However, if you choose to turn on the electric fans at the same time to help increase wind velocity, you can set the temperature at 28° C -30° C to achieve the level of thermal comfort and save your electricity bills as well

4. Locate cabinets or wardrobes against the wall either in the east or in the west

Instead of letting the heat from the sunlight coming through the wall and pass into the room directly, putting wardrobes against the wall either in the east or in the west will help reduce the heat coming into the room. However, this method might not suit with glass walls of it might cause a problem if there are non-insulated or easily-melted things stored in the wardrobes.

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[66] J. Pavungkarat, **Considerations for purchasing air-conditioners**, 2003

5. Keep windows and doors shut while air-conditioners are not operated

When air-conditioners are not operated and windows and doors are shut properly, heat and dampness unlikely increase nor store in the room, including in carpets, curtains, walls and furniture. On the other hand, if you leave them opened, air-conditioners' workload will increase to get rid of stored heat and dampness in the room first.

6. Remove some electrical appliances

Removing some appliances, such as, refrigerators, photo-copier machines, coolers, hotters, cookers, or vending machines, will help reduce heat from operation.

7. Turn off the lights and appliances when not necessary
Undoubtedly, leaving them on when not necessary will create more workload of air-conditioners.

8. Avoid smoking in the air-conditioned room

Smoking in the air-conditioned room will not only cause more workload of air-conditioners but also increase dusts (from ashes) accumulated in their coils.

9. Wear comfortable clothes

Wearing comfortable clothes will help reduce discomfort from heat and sweats.

10. Always shut windows and doors properly

If windows and doors are not shut properly, i.e., allowing gaps or room, external heat or humidity will leak into the room. As a result, air-conditioners work heavier than usual.

11. Close the curtains

Closing the curtains will help reduce external heat and also reflect the heat , thus saving energy of air-conditioners.

Appendix D: A user guide

What is a data logger?

A data logger is an electronic instrument that records measurements (temperature, relative humidity, light intensity, on/off, open/closed, voltage, pressure and events) over time. Typically, data loggers are small, battery-powered devices that are equipped with a microprocessor, data storage and sensor. Most data loggers utilize turn-key software on a personal computer to initiate the logger and view the collected data.

How to place HOBO?

1. **Outdoor monitoring**
- Place away from direct sunlight
- Place in a sheltered area where HOBO will not get wet

2. **Without air conditioned room monitoring**
- Place away from direct sunlight
- Avoid from electric appliances
- Put at head height level

3. **With air conditioned room monitoring**
- Place away from direct sunlight
- Avoid from electric appliances
- Put at head height level
- Avoid direct cold air form air conditioning unit

4. **Air conditioning unit monitoring**
- Face the sensor to the outlet where cold air is blown out

Mounting Options: There are three options for mounting it on location: a magnet, hook and loop tape, and double-sided tape. These can be stuck on the back of your HOBO. When using the magnet, note that it works best on flat surfaces.

Keep it Dry: Your HOBO data logger is meant for **indoor use only** and can be permanently damaged by corrosion if it gets wet. Protect it from water or condensation, which will damage the RH sensor. If the sensor does get wet it will need to be replaced.

Figure 01: HOBO series H8

My logger got wet, what should I do?

If the logger was exposed to salt water, remove the board from the case, remove the battery from the board and rinse the board under clean water. Dry the board completely using a hair dryer. If the logger was exposed to fresh water there is no need to rinse the board, you will just need to dry the logger completely.

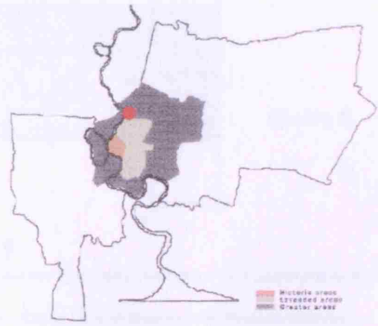
Appendix E: Building performance assessment: measurement results

Building performance assessment: Case 01

Aerial photo of the monitored building – case 01[67]

1.1 Building description

Three blocks of 15-storey apartment buildings are situated slightly off from the city centre with good transportation links to the centre. The commissioned project was approximately completed in mid of 1990's. The buildings mainly consist of units of studio apartment where two levels above ground level are used for car parking space as well as for facilities with outdoor swimming poor.



Location of the building

1.2 Orientation and building form

The building form is simply designed in box shapes in order to create as many as possible of accommodation units which reflects to demands in accommodations and maximizes the land use. The long axis of buildings faces east and west without provided solar shading. Overshadow always occurs to the surrounding buildings where are two to four-storey buildings.

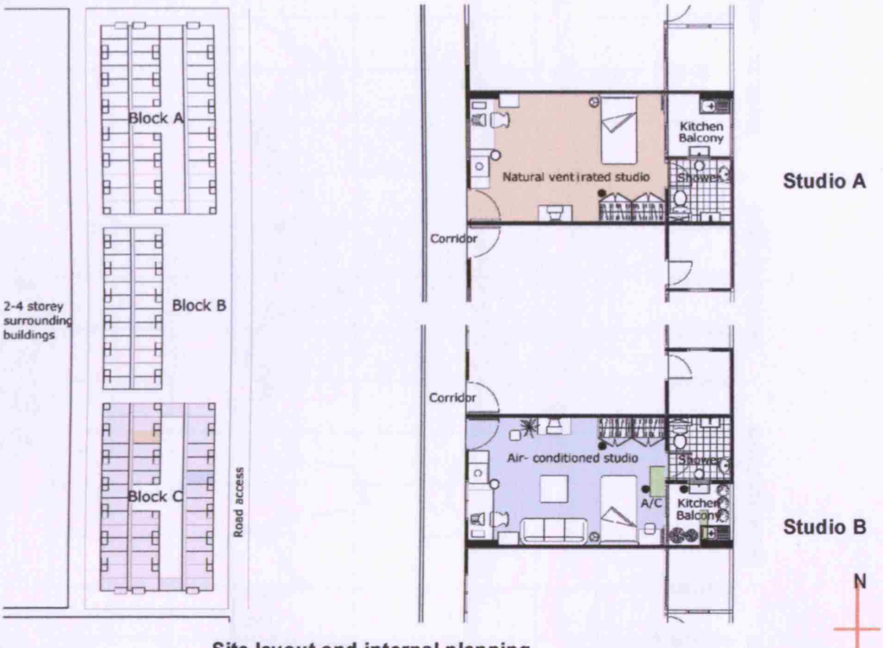
North facade of building

[67] Source by Google Earth, 2005

1.3 Construction and materials

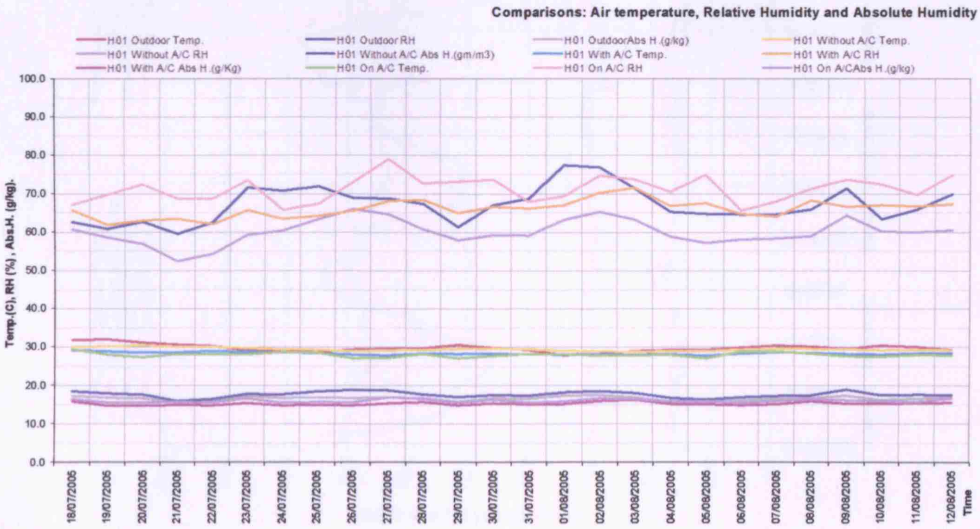
The buildings have a concrete structure with flat roof. Bricks and concrete blocks are typical constructed for external and internal walls with render finishing. White colour is painted on all sides of external walls.

East façade of building



Site layout and internal planning

(Key colour: Orange = Natural ventilated rooms, Blue = Air-conditioned rooms, Green = Air-conditioners (split type), Black dot = Data logger positions)



Relations of dry-bulb temperature (° C), relative humidity(%) and absolute humidity [68](g/kg)

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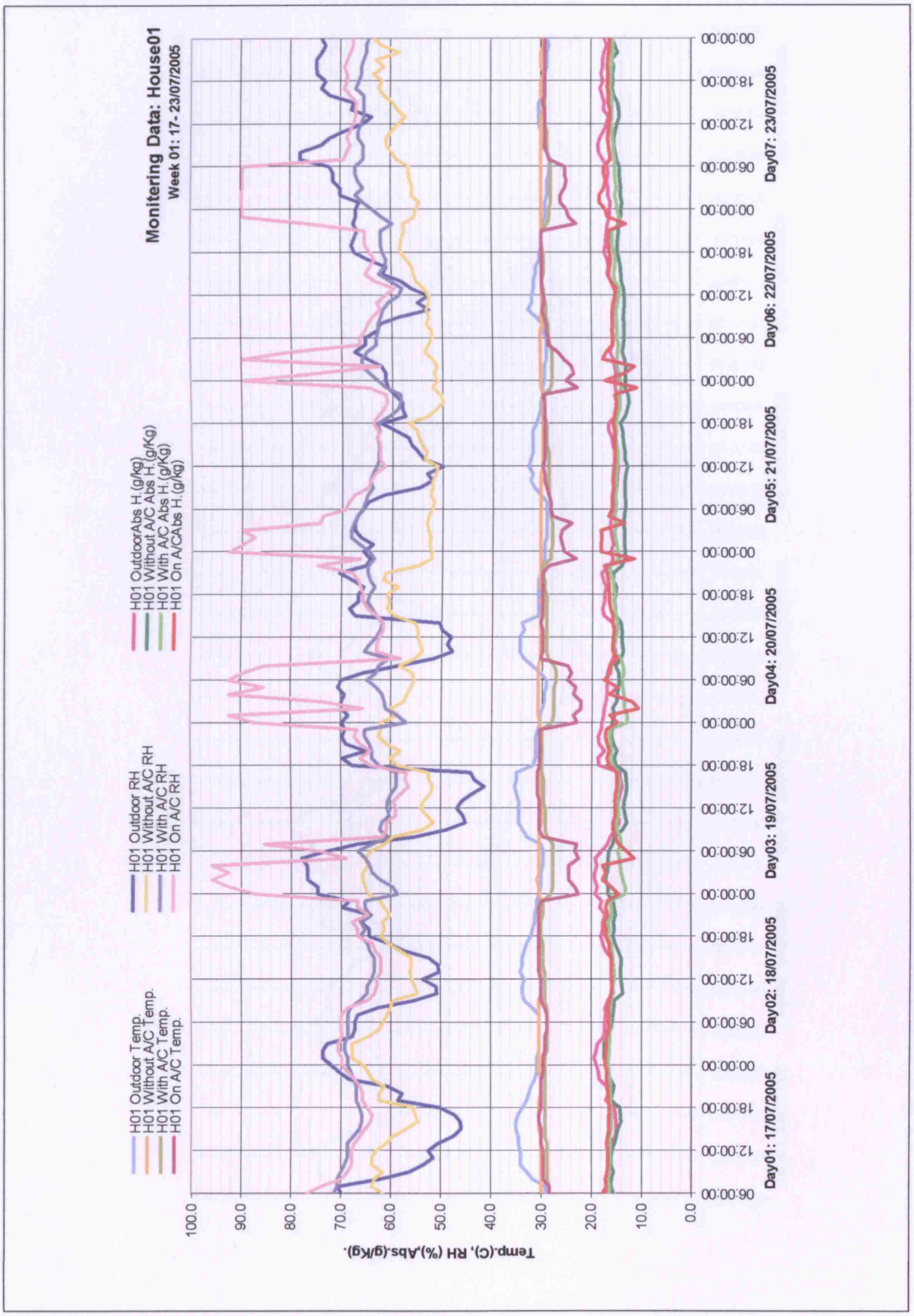
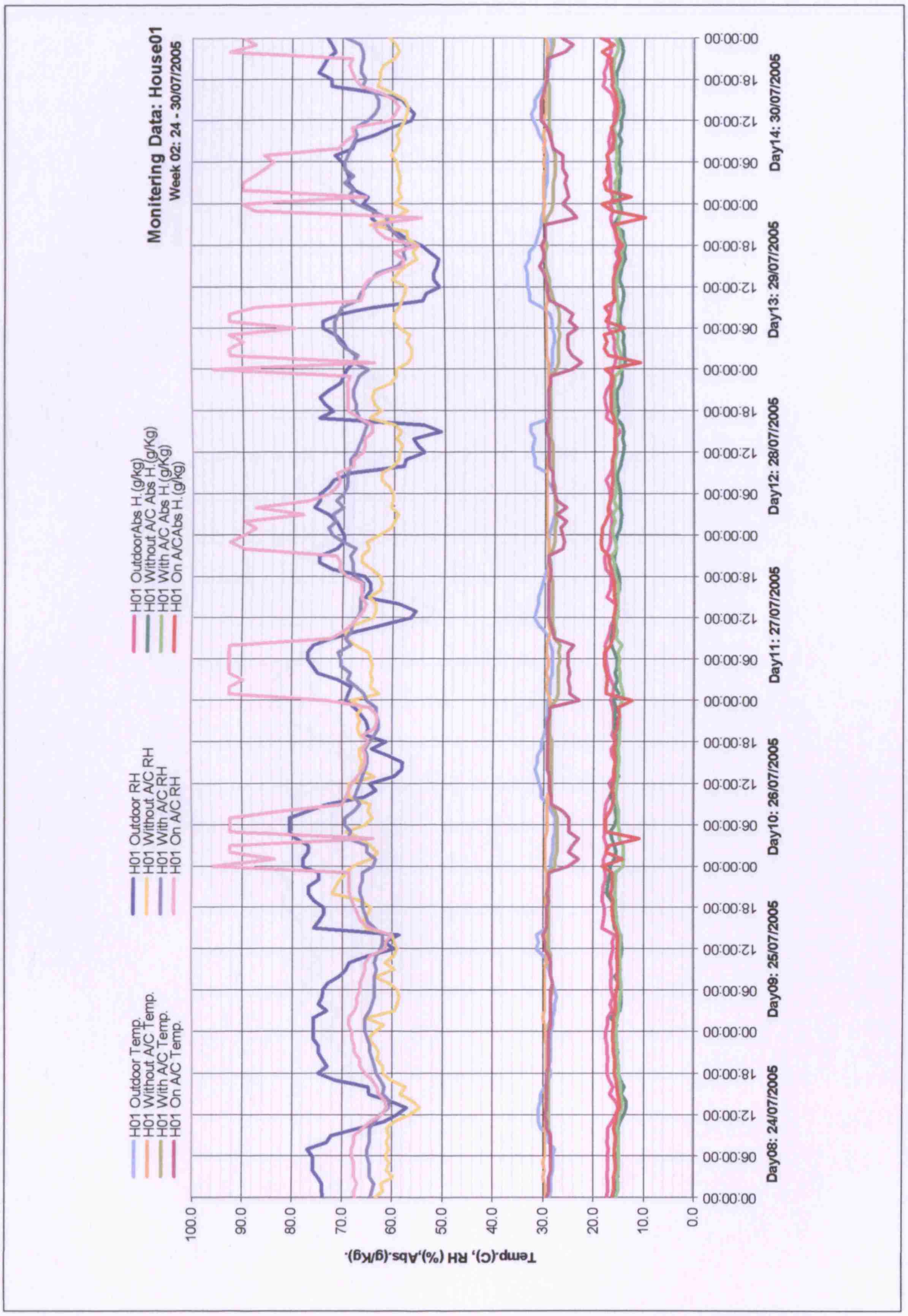
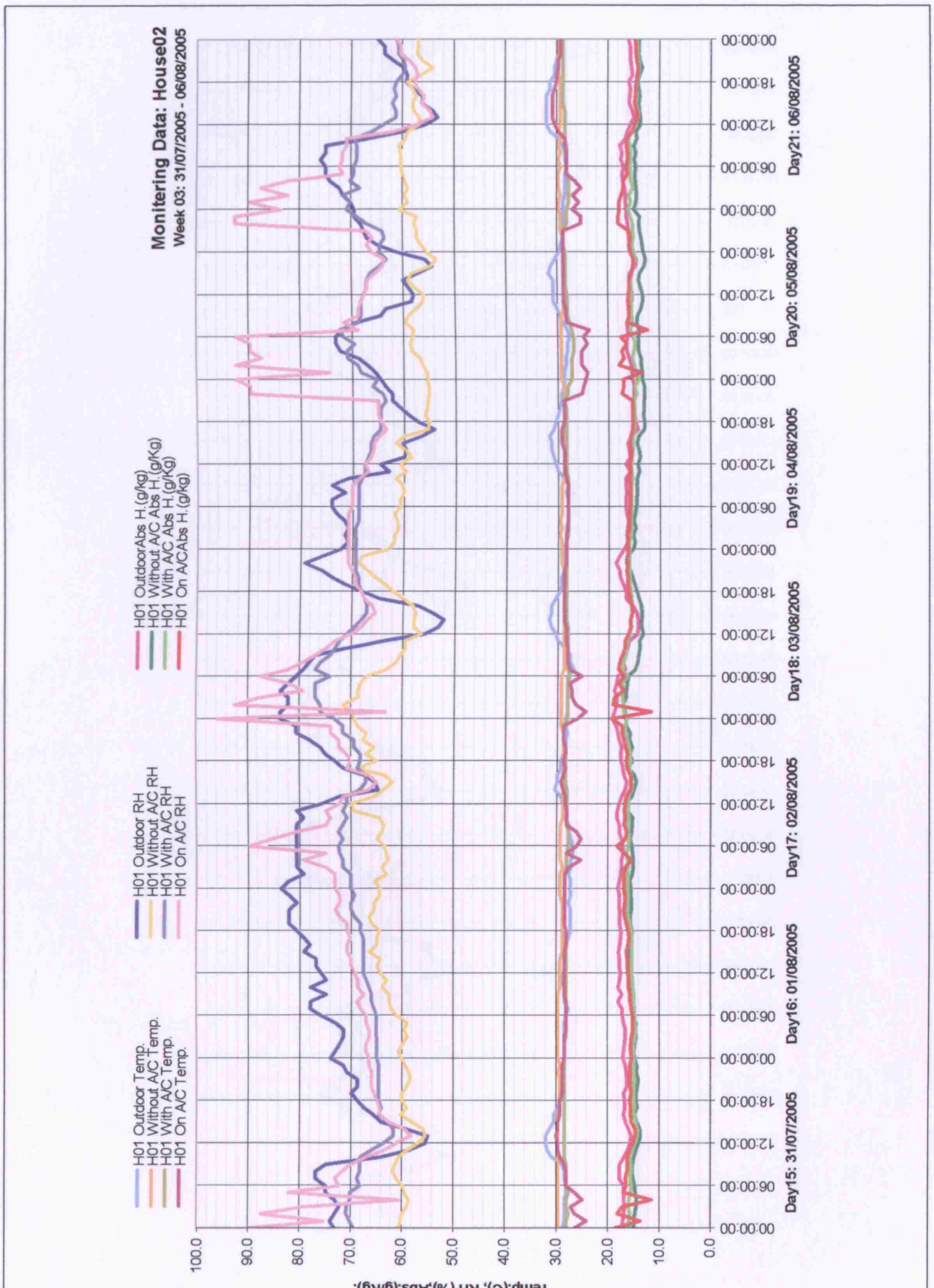
[68] **Absolute humidity** is a measure of the amount of moisture in the air


Monitering Data: House01
Week 01: 17- 23/07/2005
H01 Outdoor Temp.
H01 Without A/C Temp.
H01 With A/C Temp.
H01 On A/C Temp.
H01 Outdoor RH
H01 Without A/C RH
H01 With A/C RH
H01 On A/C RH
H01 OutdoorAbs H.(g/kg)
H01 Without A/C Abs H.(g/Kg)
H01 With A/C Abs H.(g/Kg)
H01 On A/CAbs H.(g/kg)
Temp.(C), RH (%),Abs.(g/Kg).
Day01: 17/07/2005
Day02: 18/07/2005
Day03: 19/07/2005
Day04: 20/07/2005
Day05: 21/07/2005
Day06: 22/07/2005
Day07: 23/07/2005

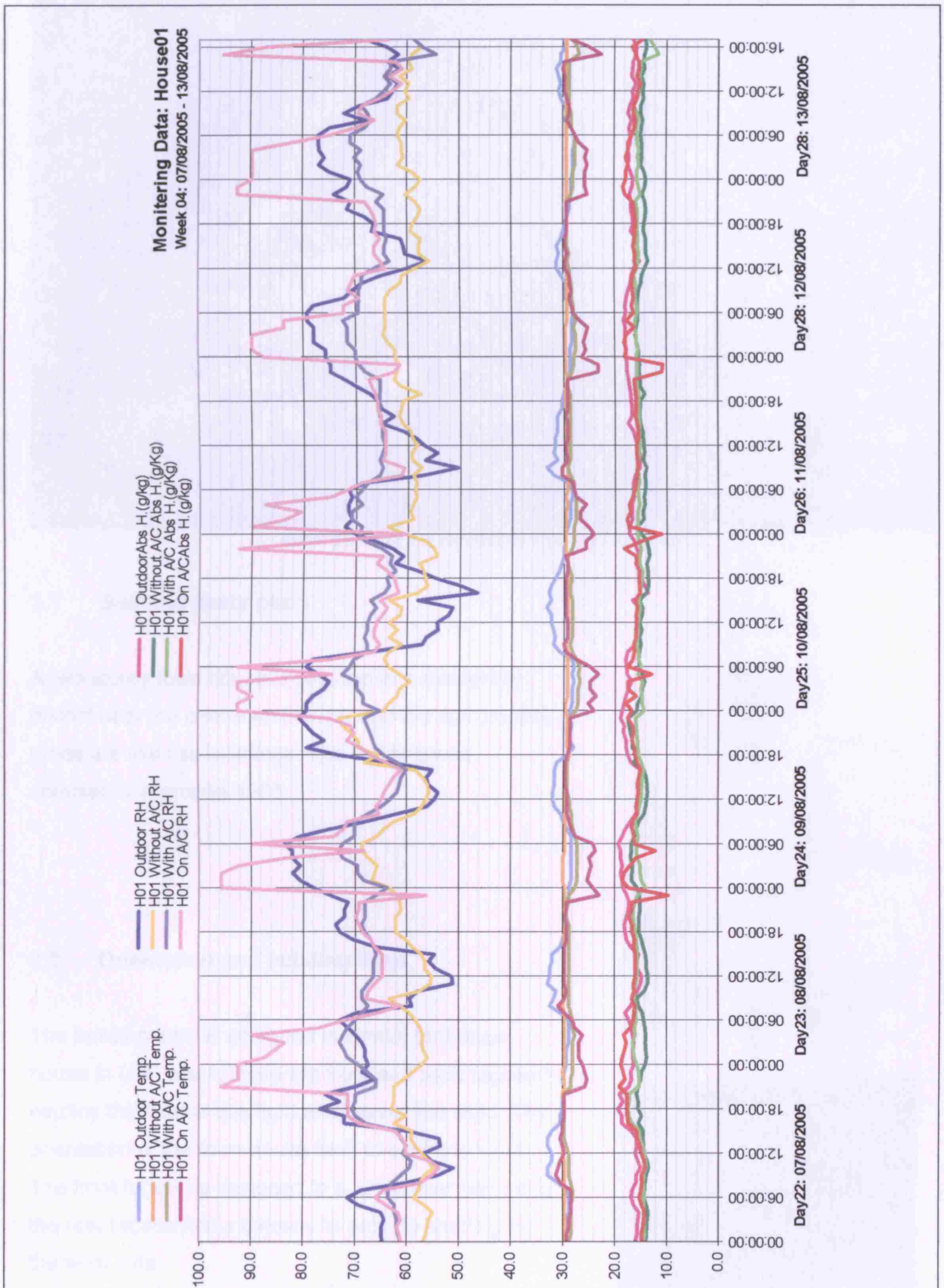


Monitering Data: House01
Week 02: 24 - 30/07/2005
H01 Outdoor Temp.
H01 Without A/C Temp.
H01 With A/C Temp.
H01 On A/C Temp.
H01 Outdoor RH
H01 Without A/C RH
H01 With A/C RH
H01 On A/C RH
H01 OutdoorAbs H.(g/kg)
H01 Without A/C Abs H.(g/kg)
H01 With A/C Abs H.(g/kg)
H01 On A/CAbs H.(g/kg)
Temp.(C), RH (%),Abs.(g/Kg).
Day08: 24/07/2005
Day09: 25/07/2005
Day10: 26/07/2005
Day11: 27/07/2005
Day12: 28/07/2005
Day13: 29/07/2005
Day14: 30/07/2005

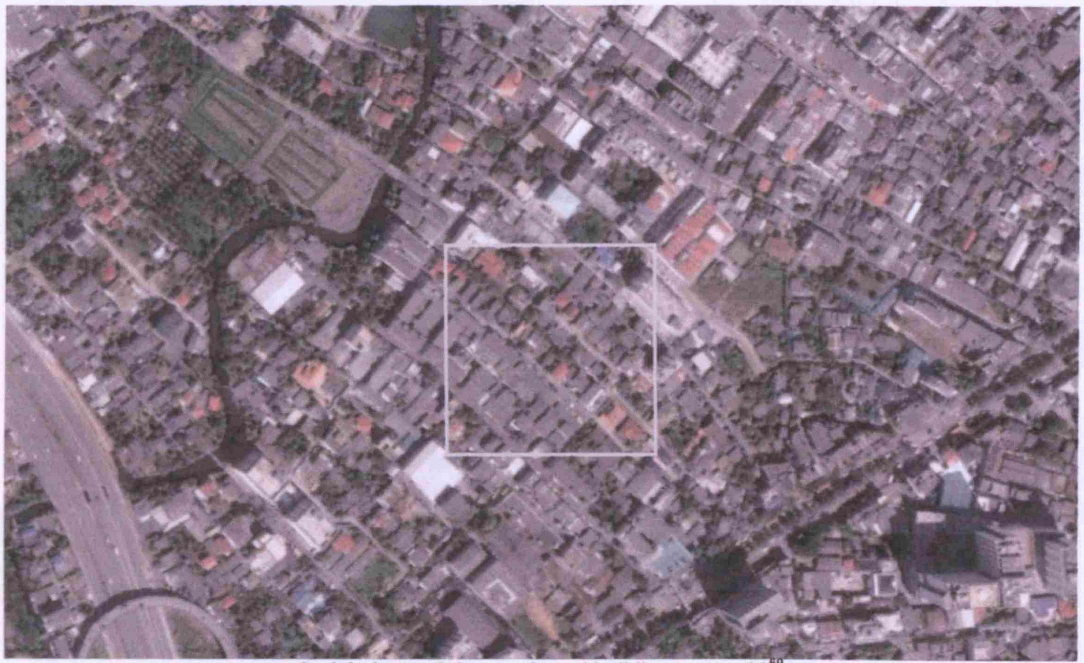
Building performance assessment: Monitoring data of case 01 **Week 03: 31 - 06/08/2005**



Building performance assessment: Monitoring data of case 01 **Week 04: 07 - 13/08/2005**

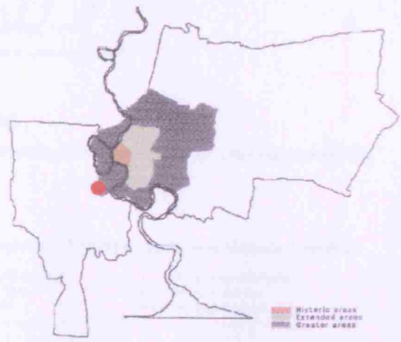


Environment assessment fact sheet: Case 02



Aerial photo of the monitored building – case 02[69]

2.1 Building description



Location

A two-storey town house is situated in a residential district near the centre on the city and the surrounding areas are low rise buildings. The building was completed in around 1985.

2.2 Orientation and building form

Front Façade of building

The building form is designed in similar to terrace house in U.K. where there are front and back façade for employ the natural day light and prevail the wind. The orientation of the town house face to east and west. The front façade is designed to a small over hang and the rear façade has a balcony to provide shading on the west side.

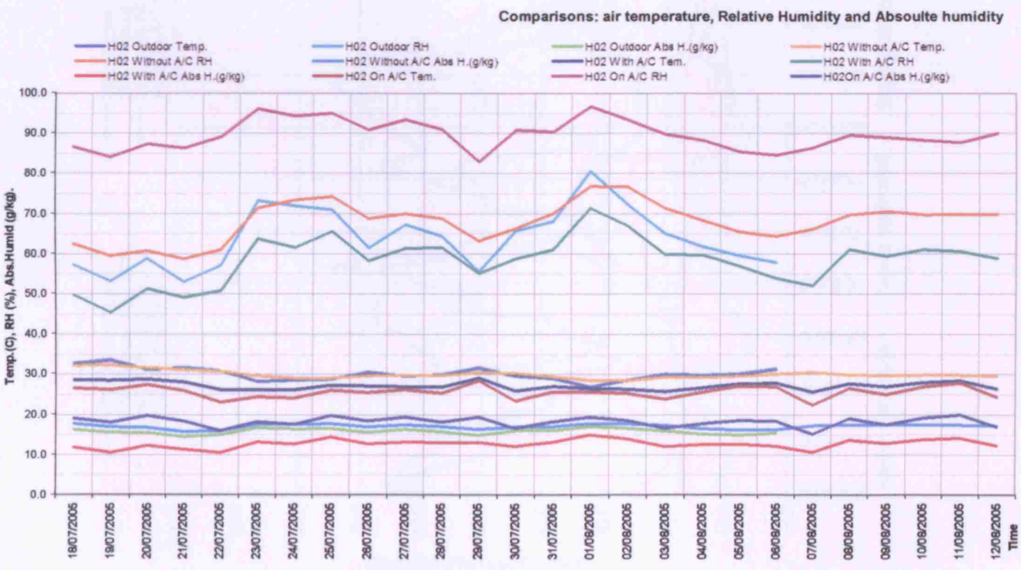
[69] Source by Google Earth, 2005

2.3 Construction and materials

The buildings have a concrete structure with a tilted roof. Bricks and concrete blocks are typical constructed for external and internal walls with render finishing. Light lemon green colour is painted on external walls.

Site layout and internal planning

(Key colour: Orange = Natural ventilated rooms, Blue = Air-conditioned rooms, Green = Air-conditioners (split type), Black dot = Data logger positions)



Relations of dry-bulb temperature (^{o} C), relative humidity(%) and absolute humidity [70](g/kg)

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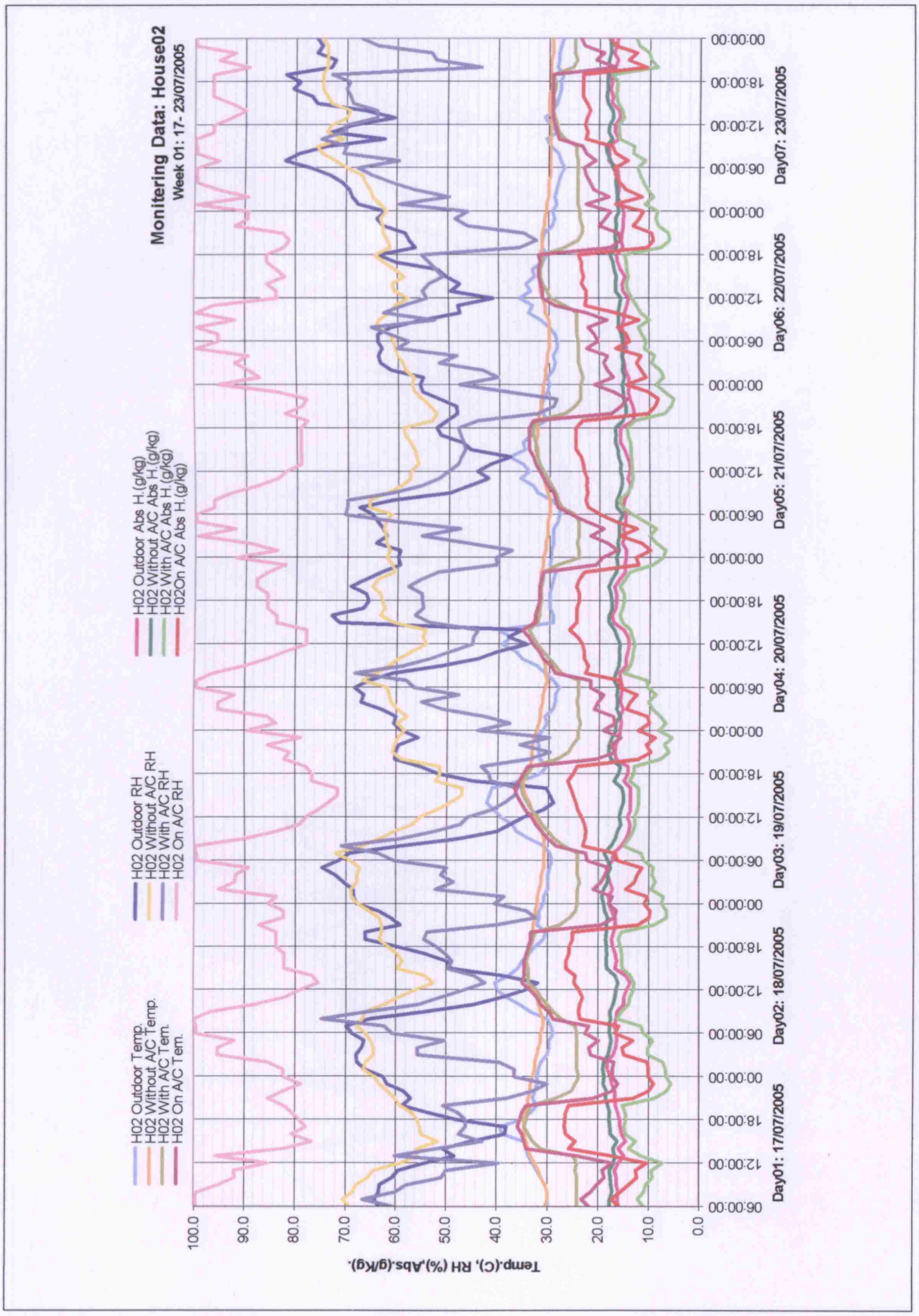
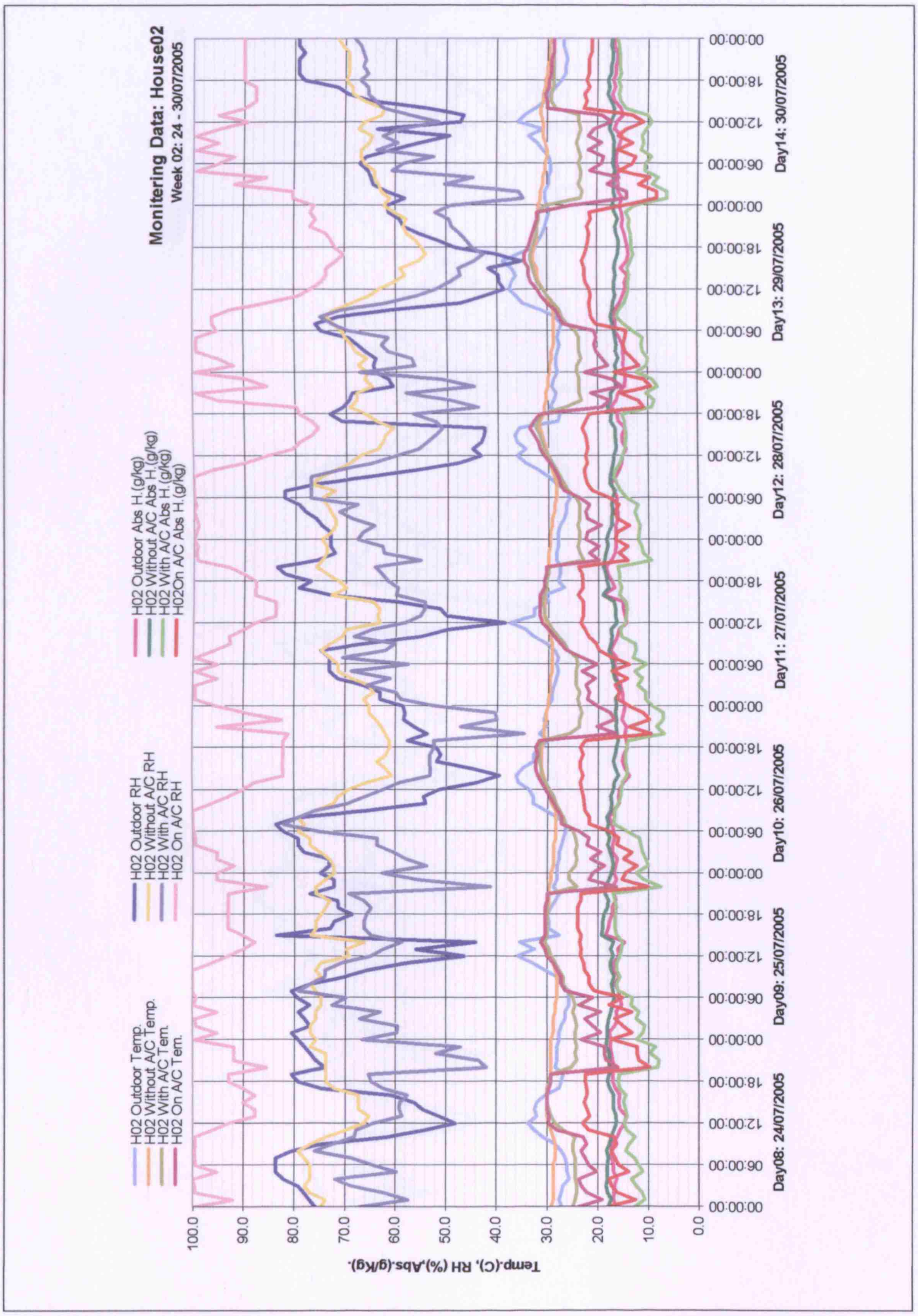
[70] **Absolute humidity** is a measure of the amount of moisture in the air


Monitering Data: House02
Week 01: 17- 23/07/2005
H02 Outdoor Temp.
H02 Without A/C Temp.
H02 With A/C Tem.
H02 On A/C Tem.
H02 Outdoor RH
H02 Without A/C RH
H02 With A/C RH
H02 On A/C RH
H02 Outdoor Abs H.(g/kg)
H02 Without A/C Abs H.(g/kg)
H02 With A/C Abs H.(g/kg)
H02On A/C Abs H.(g/kg)
Temp.(C), RH (%),Abs.(g/Kg).
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
06:00:00
12:00:00
18:00:00
00:00:00
Day01: 17/07/2005
Day02: 18/07/2005
Day03: 19/07/2005
Day04: 20/07/2005
Day05: 21/07/2005
Day06: 22/07/2005
Day07: 23/07/2005


Monitering Data: House02
Week 02: 24 - 30/07/2005
H02 Outdoor Temp.
H02 Without A/C Temp.
H02 With A/C Tem.
H02 On A/C Tem.
H02 Outdoor RH
H02 Without A/C RH
H02 With A/C RH
H02 On A/C RH
H02 Outdoor Abs H.(g/kg)
H02 Without A/C Abs H.(g/kg)
H02 With A/C Abs H.(g/kg)
H02On A/C Abs H.(g/kg)
Temp.(C), RH (%),Abs.(g/Kg).
100.0
90.0
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06:00:00
12:00:00
18:00:00
Day08: 24/07/2005
Day09: 25/07/2005
Day10: 26/07/2005
Day11: 27/07/2005
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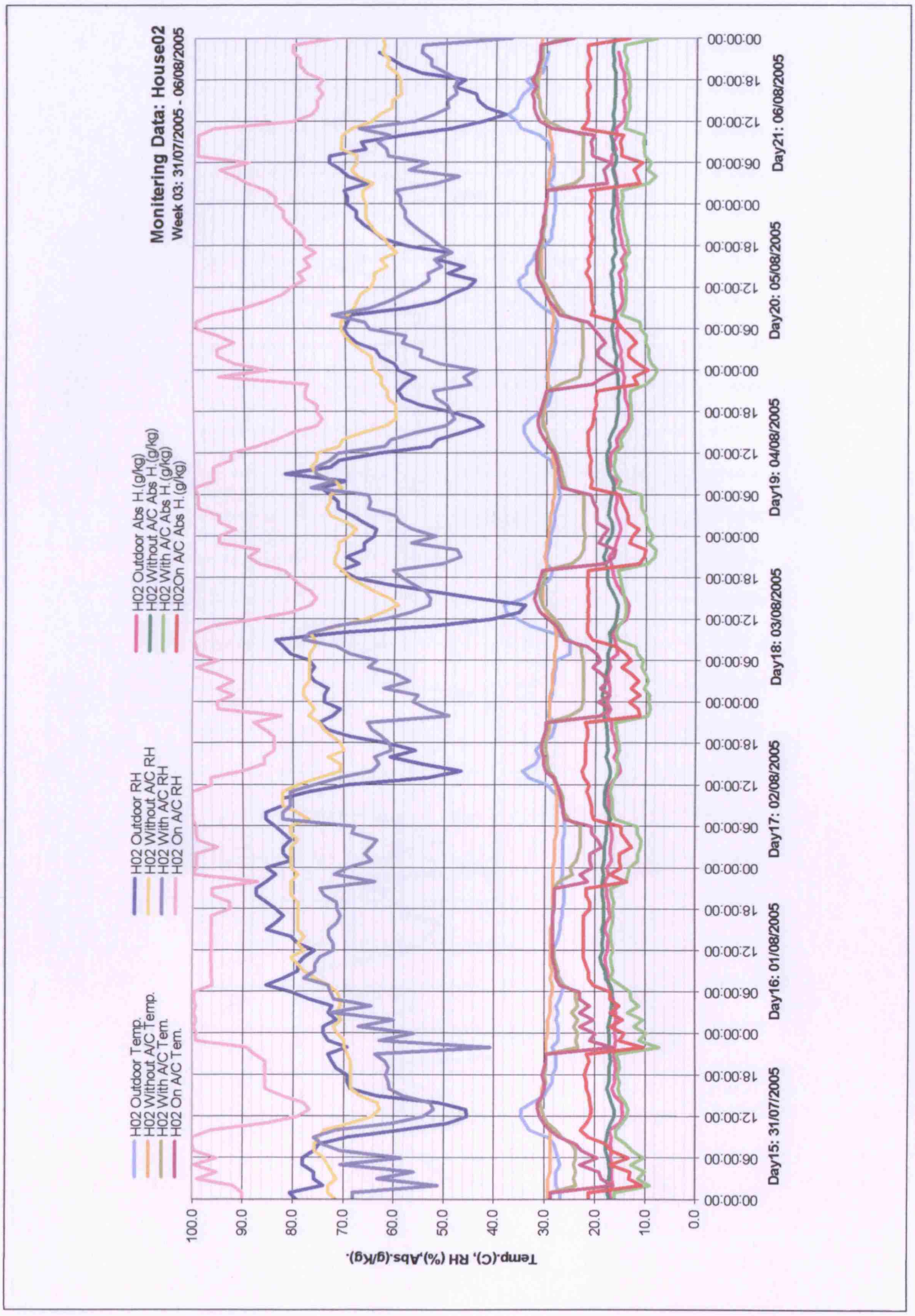
Day13: 29/07/2005
Day14: 30/07/2005


Monitering Data: House02
Week 03: 31/07/2005 - 06/08/2005
H02 Outdoor Temp.
H02 Without A/C Temp.
H02 With A/C Tem.
H02 On A/C Tem.
H02 Outdoor RH
H02 Without A/C RH
H02 With A/C RH
H02 On A/C RH
H02 Outdoor Abs H.(g/kg)
H02 Without A/C Abs H.(g/kg)
H02 With A/C Abs H.(g/kg)
H02On A/C Abs H.(g/kg)
Temp.(C), RH (%),Abs.(g/Kg).
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
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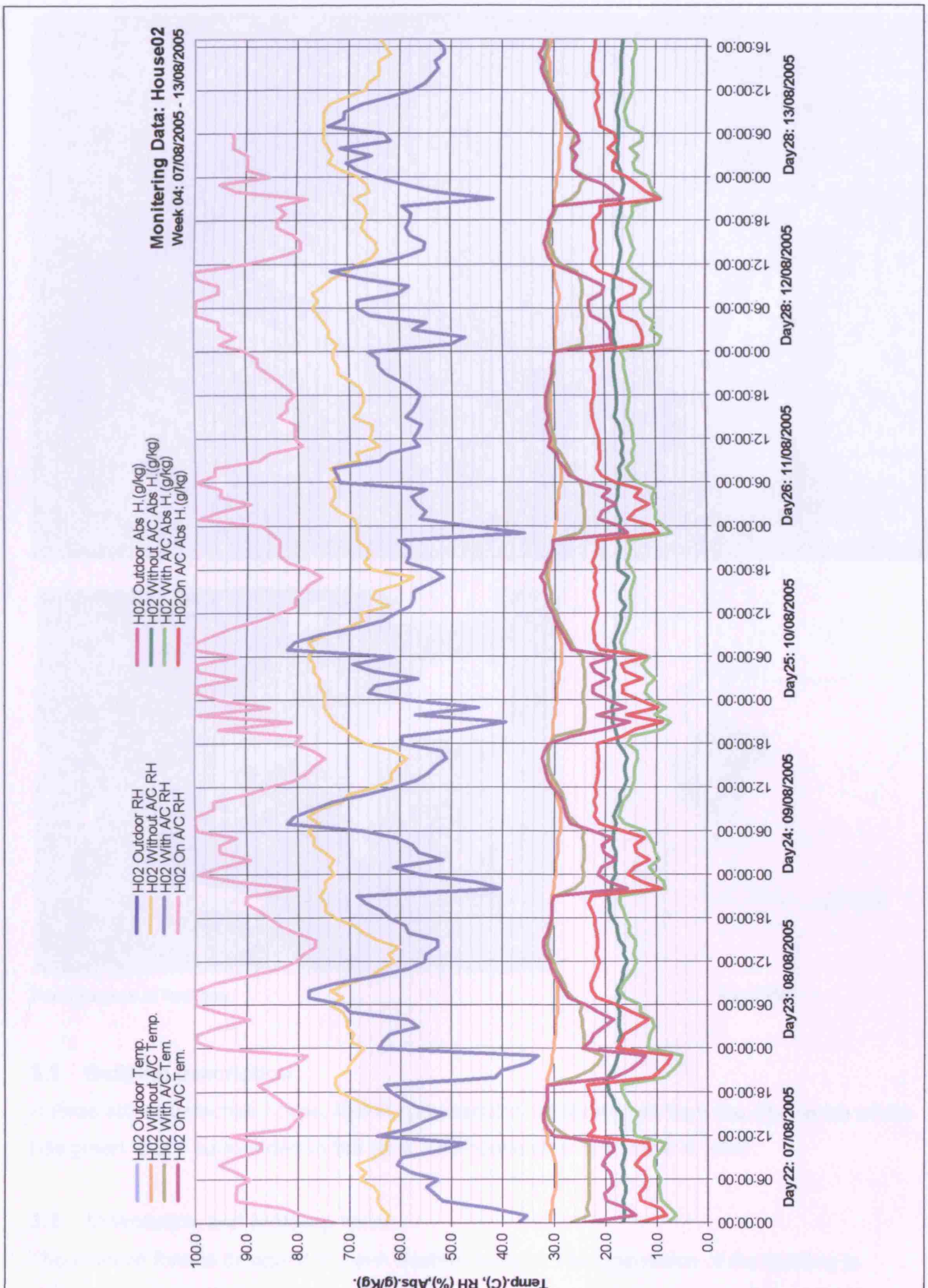
00:00:00
06:00:00
12:00:00
18:00:00
Day15: 31/07/2005
Day16: 01/08/2005
Day17: 02/08/2005
Day18: 03/08/2005
Day19: 04/08/2005
Day20: 05/08/2005
Day21: 06/08/2005


Monitering Data: House02
Week 04: 07/08/2005 - 13/08/2005
H02 Outdoor Temp.
H02 Without A/C Temp.
H02 With A/C Tem.
H02 On A/C Tem.
H02 Outdoor RH
H02 Without A/C RH
H02 With A/C RH
H02 On A/C RH
H02 Outdoor Abs H.(g/kg)
H02 Without A/C Abs H.(g/kg)
H02 With A/C Abs H.(g/kg)
H02On A/C Abs H.(g/kg)
Temp.(C), RH (%),Abs.(g/Kg).
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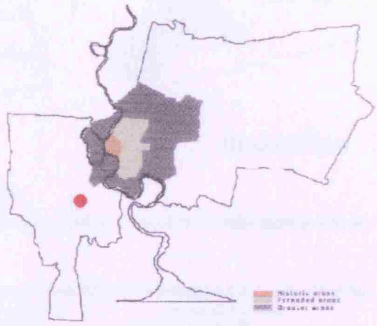
0.0
00:00:00
06:00:00
12:00:00
18:00:00
Day22: 07/08/2005
Day23: 08/08/2005
Day24: 09/08/2005
Day25: 10/08/2005
Day26: 11/08/2005
Day28: 12/08/2005
Day28: 13/08/2005

Environment assessment fact sheet: Case 03



Front Façade of building **Location**

3.1 Building description

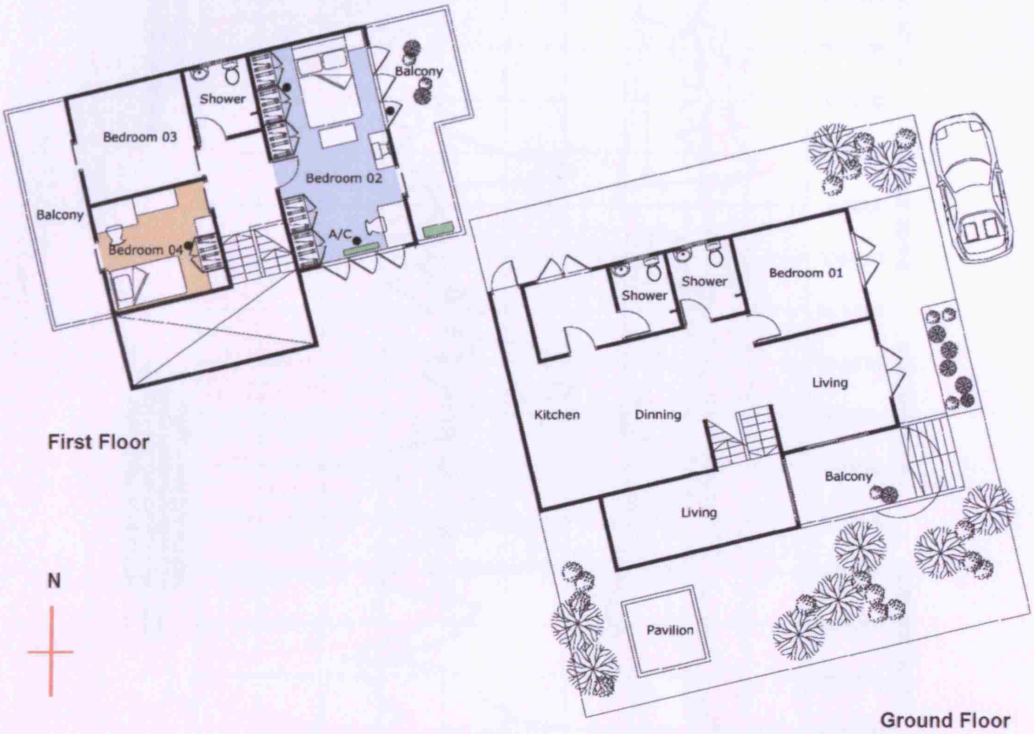
A three-storey detached house, including basement, is situated off from the city centre where has green space surrounded in the area. The house was completed in 2002.

3.2 Orientation and building form

The building form is designed to have western feature. The orientation of the building is slightly tilted to northeast and southwest. Extensions or over hangs are used for provide and protect strong solar gain.

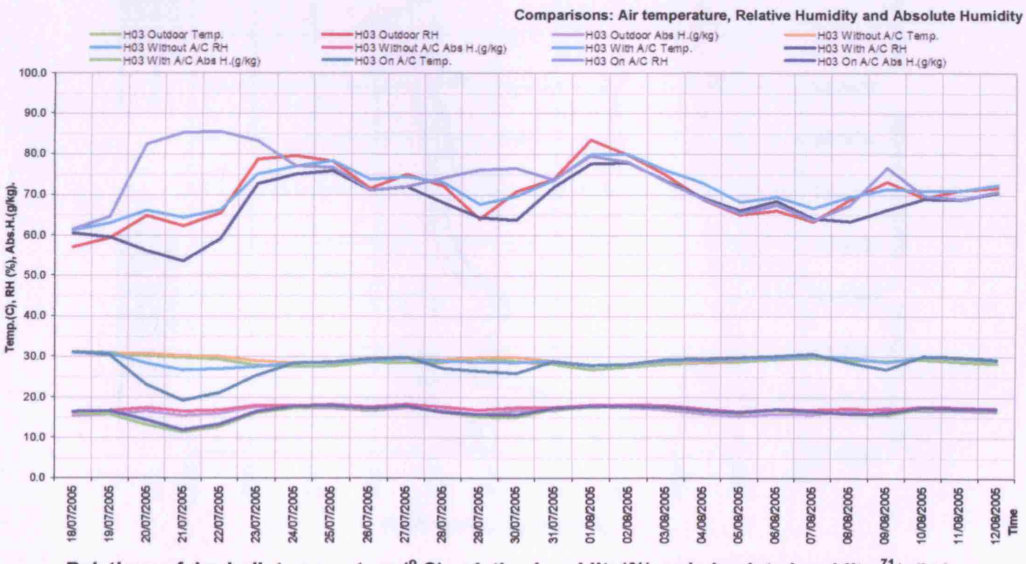
3.3 Construction and materials

The buildings have a concrete structure with a pitch roof. Bricks and concrete blocks are typical constructed for external and internal walls with render finishing. Light cream colour is painted on external walls.



Site layout and internal planning

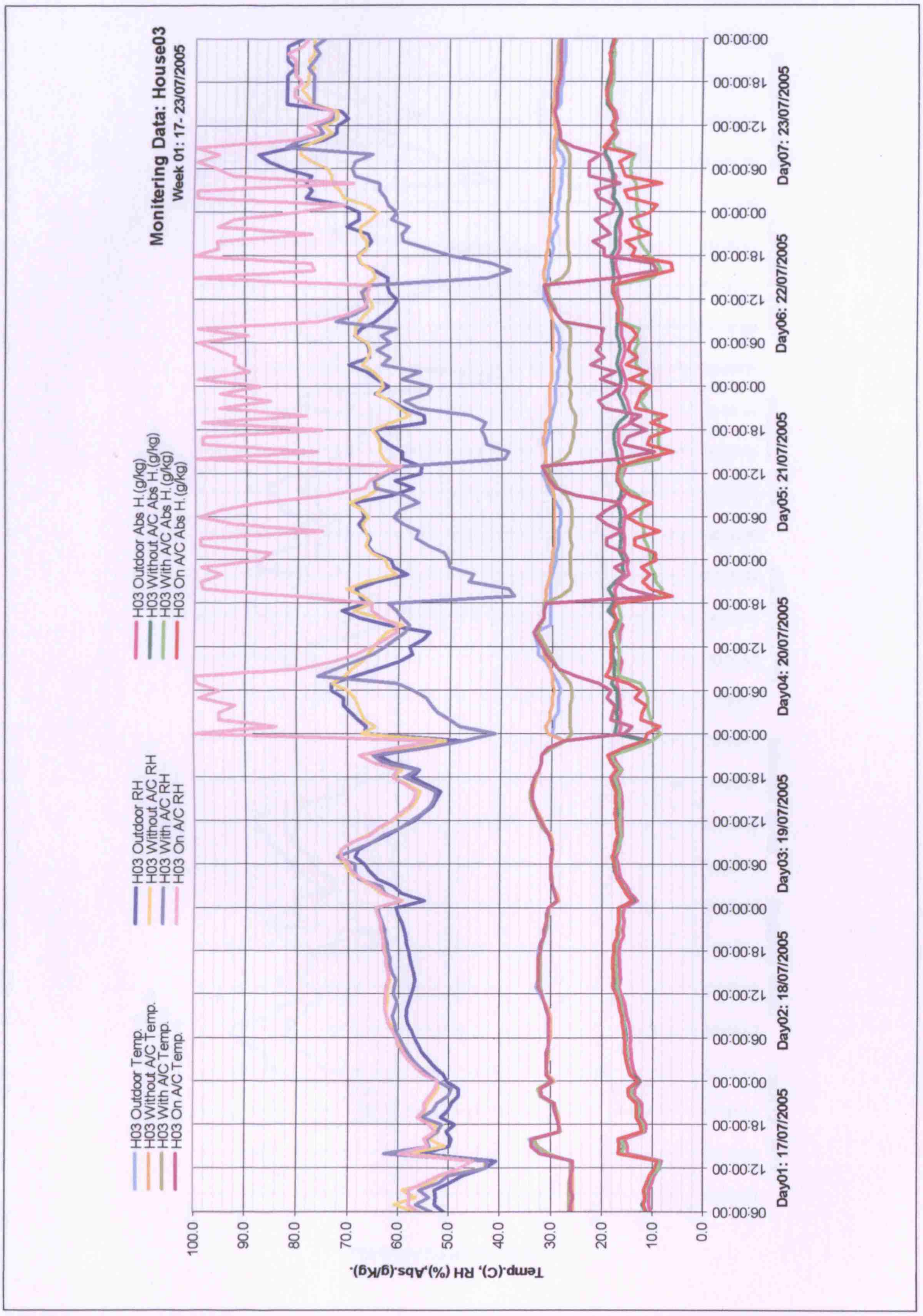
(Key colour: Orange = Natural ventilated rooms, Blue = Air-conditioned rooms, Green = Air-conditioners (split type), Black dot = Data logger positions)

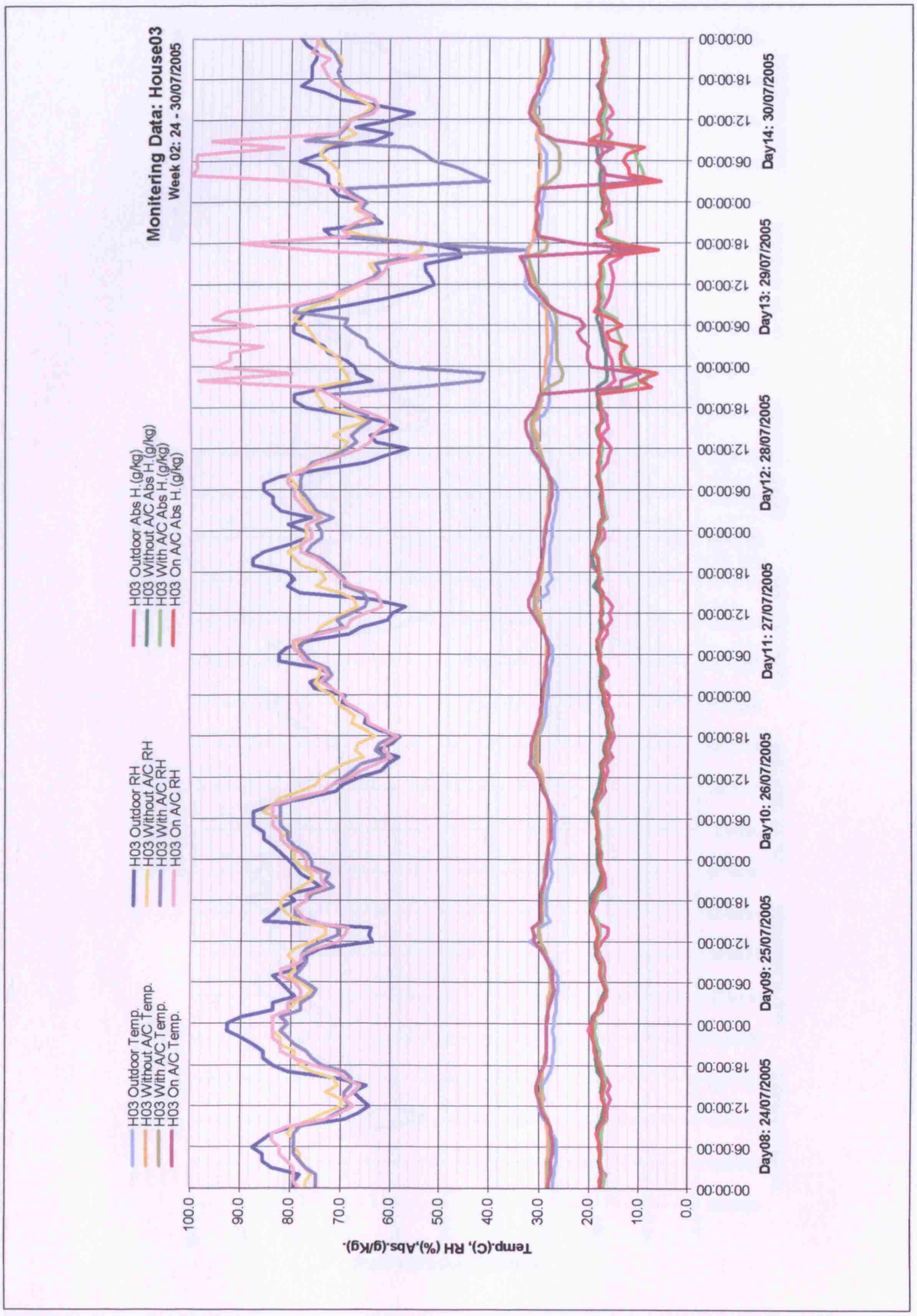


Relations of dry-bulb temperature (° C), relative humidity(%) and absolute humidity [71](g/kg)

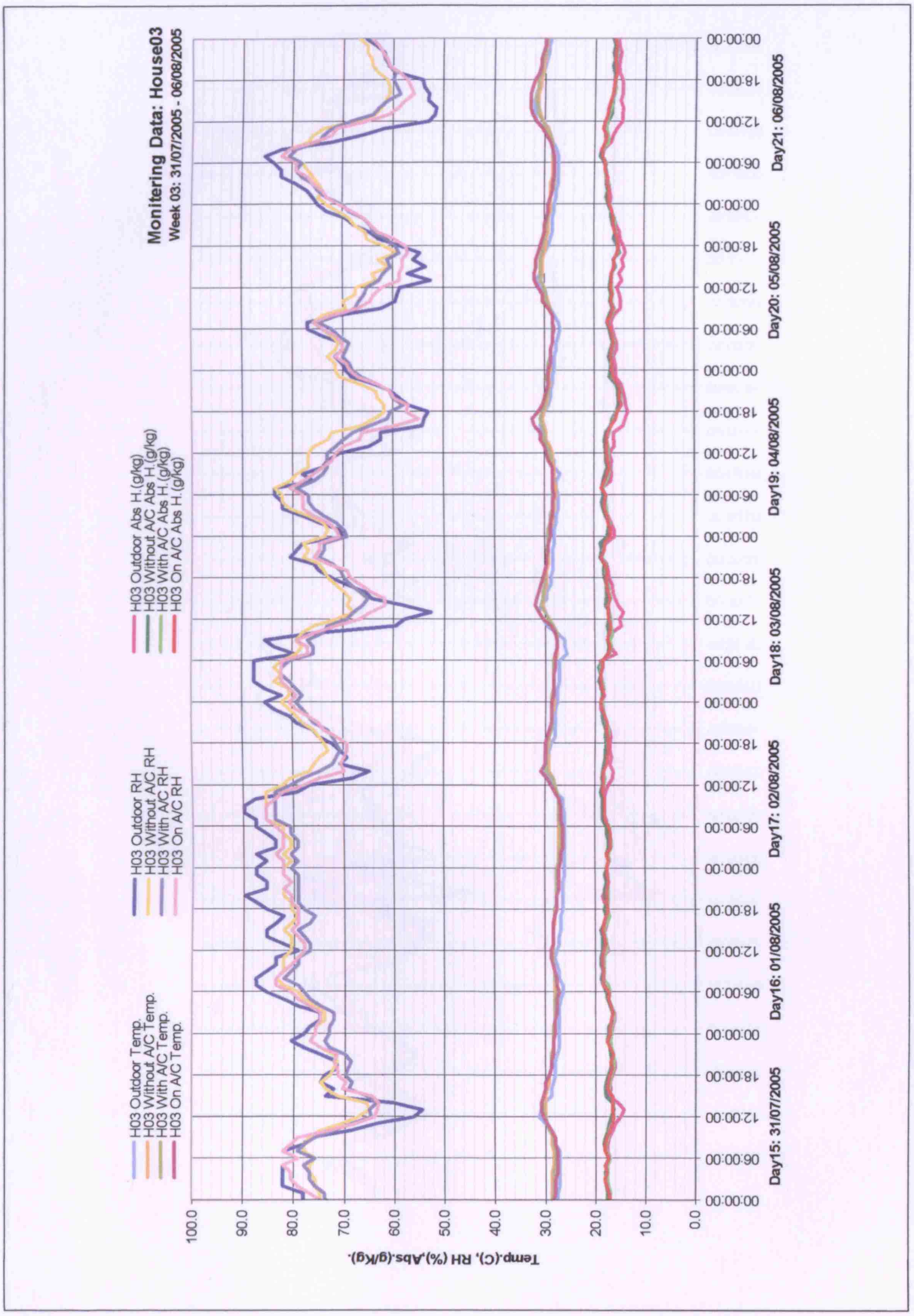
[71] **Absolute humidity** is a measure of the amount of moisture in the air

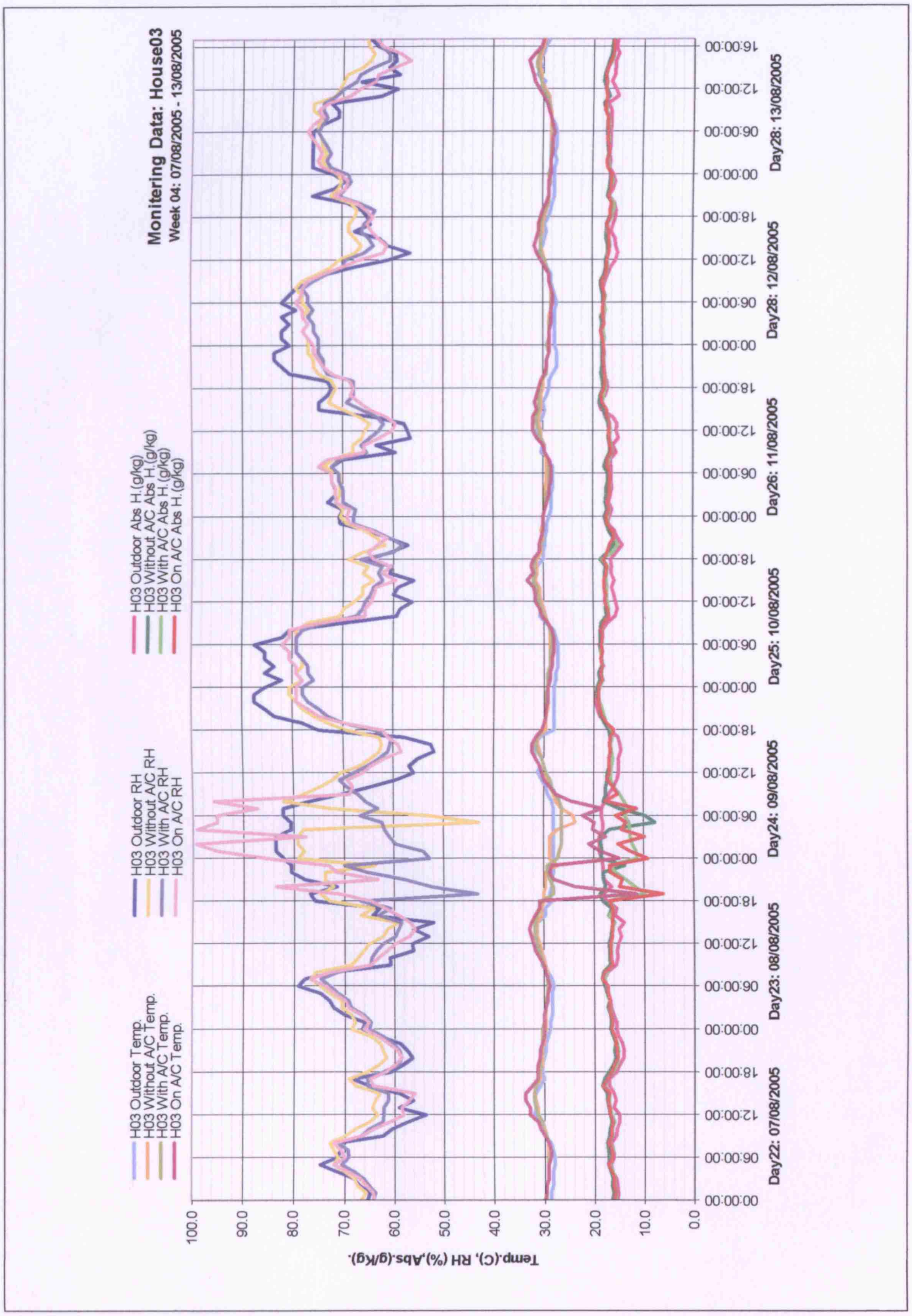
Building performance assessment: Monitoring data of case 03 **Week 01: 17 - 23/07/2005**




Monitering Data: House03
Week 02: 24 - 30/07/2005
H03 Outdoor Temp.
H03 Without A/C Temp.
H03 With A/C Temp.
H03 On A/C Temp.
H03 Outdoor RH
H03 Without A/C RH
H03 With A/C RH
H03 On A/C RH
H03 Outdoor Abs H.(g/kg)
H03 Without A/C Abs H.(g/kg)
H03 With A/C Abs H.(g/kg)
H03 On A/C Abs H.(g/kg)
Temp.(C), RH (%),Abs.(g/Kg).
Day08: 24/07/2005
Day09: 25/07/2005
Day10: 26/07/2005
Day11: 27/07/2005
Day12: 28/07/2005
Day13: 29/07/2005
Day14: 30/07/2005

Building performance assessment: Monitoring data of case 03   Week 03: 31 - 06/08/2005




Monitering Data: House03
Week 04: 07/08/2005 - 13/08/2005
H03 Outdoor Temp.
H03 Without A/C Temp.
H03 With A/C Temp.
H03 On A/C Temp.
H03 Outdoor RH
H03 Without A/C RH
H03 With A/C RH
H03 On A/C RH
H03 Outdoor Abs H.(g/kg)
H03 Without A/C Abs H.(g/kg)
H03 With A/C Abs H.(g/kg)
H03 On A/C Abs H.(g/kg)
Temp.(C), RH (%),Abs.(g/Kg).
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
Day22: 07/08/2005
Day23: 08/08/2005
Day24: 09/08/2005
Day25: 10/08/2005
Day26: 11/08/2005
Day28: 12/08/2005
Day28: 13/08/2005